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WELCOME



I hate this time of year. While the bright lights of Christmas have faded, the grey days and long nights have blurred into one featureless smudge. Plus, my heating bill is getting worryingly large. I'm sure I'm not the only one who feels this way, so consider this month's magazine something of a 'feel good issue'. The magazine's features have been chosen because we hope they'll brighten up your February just a little.

First up, we're sharing the science that makes us feel better about the future. On p37 we talk to the scientists working to overcome some of humankind's biggest challenges – famine, climate change, antibiotic resistance and mass extinction – and find out why their innovative work makes them hopeful about our future.

If that doesn't leave a smile on your face, then the story of Kirk Rutter should. At the age of 47, after the death of his mother, he fell into a long and untreatable depression, until a groundbreaking, experimental treatment rebooted his brain and helped him get back on track. Discover the science that changed his life on p56.

And finally, if you prefer a bit of escapism to cheer you up, we asked the experts for an alternate history lesson. On p62, we find out what life would have been like if the asteroid that killed off the dinosaurs had arrived just a few minutes earlier...

Enjoy the issue!

Daniel Bennett

Daniel Bennett, Editor

IN THIS ISSUE



SUSAN FINKBEINER

Butterfly collector, catwalk model and jungle explorer Susan seems to have taken all the good jobs! Read more about her incredible career. → p98



ALLA KATSNELSON

Alla has been reporting on health and science for over a decade. This issue, she investigates the discoveries that could help leave animal testing in the past. → p73



CASSANDRA QUAVE

At age three, Cassandra was hospitalised for months after an MRSA infection. We look at her work to create a new way to fight antibiotic-resistant superbugs. → p37



A quail laid an egg in space in 1990 → p85

WHAT WE'VE FOUND OUT THIS MONTH

Children born by Caesarean section are more likely to develop allergic diseases → p24



Part of the Whitechapel fatberg will go on display in the Museum of London this month → p95

Scientists can add nanoparticles to plants to make them glow in the dark → p20



If the asteroid that killed off the dinosaurs had hit just a few minutes earlier, it's likely there would be dinosaurs still alive today → p62

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CONTENTS

37

COVER
STORY

27



REGULARS

8 Eye opener

Stunning images from around the planet.

10 Reply

See what's been in our inbox this month...

13 Discoveries

This month's most exciting science news.

24 Michael Mosley

Our new monthly columnist investigates the microbiome.

27 Innovations

Our roundup of the best new tech and gadgets from this year's CES.

79 Helen Czerski

Helen wraps up warm to investigate the science of frost.

81 Q&A

This month: How far do germs travel when we cough? Can chickens lay eggs in space? Why is air invisible?

90 Out there

This month's best science activities.

96 Crossword

Give that grey matter a workout!

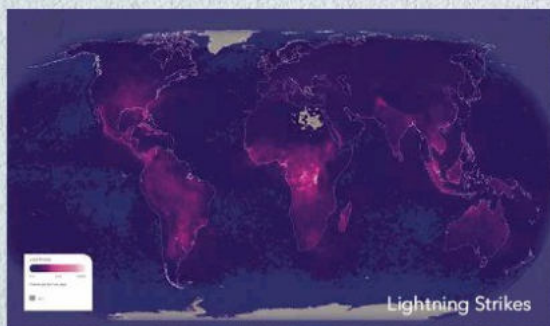
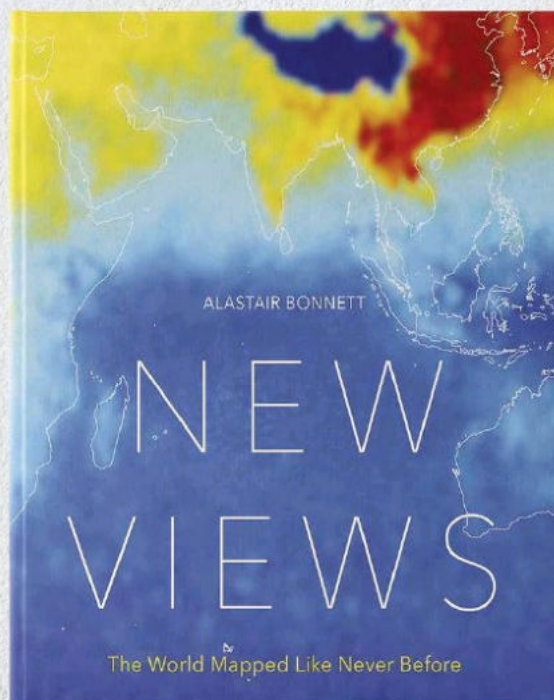
98 Life scientific

Dr Susan Finkbeiner on the diverse worlds of entomology and catwalk modelling.

54 Subscribe

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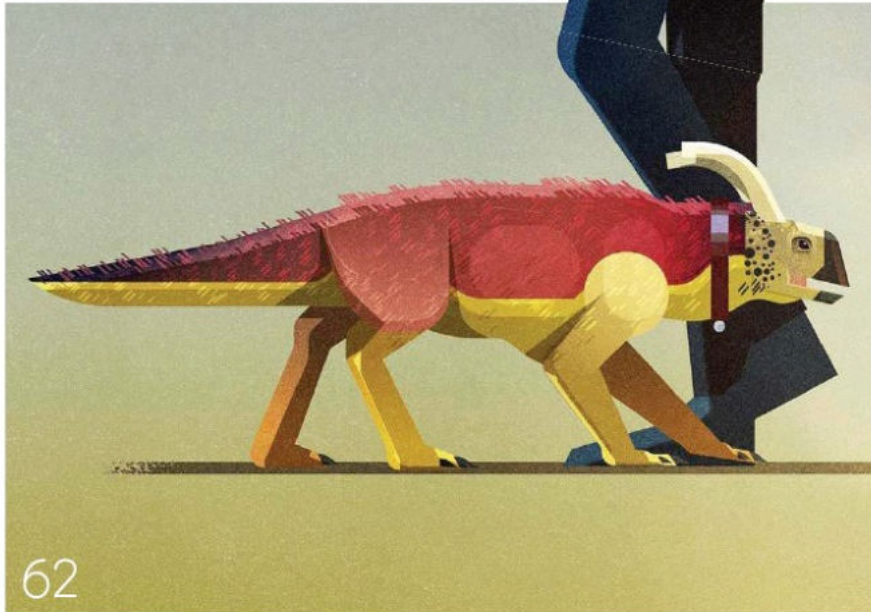
NEW VIEWS



See the world mapped like never before in this stunning geographical exploration of our world through a collection of 50 specially commissioned maps visualising the physical, political and cultural make up of our planet.

New Views travels across land, air and sea to map asteroid strikes, undersea cables, ocean rubbish. The book charts human and animal behaviour including linguistic diversity, ant populations, religious diversity and ecological footprint per capita and acknowledges globalisation by tracking Twitter relationships, critically endangered languages, problem drugs, and much more.

New Views brings together 50 captivating subjects each presented with an extraordinary map and accompanied by Alastair Bonnett's vivid, expert insight into how the planet has changed thus far and what it may look like in the future.



62

FEATURES

COVER STORY

Why the end isn't nigh

37 We meet four enterprising scientists who are tackling the world's biggest problems.

How hallucinogens reset depressed minds

56 Research suggests that the psychedelic part of magic mushrooms could help cure depression.

What if the dinosaurs never went extinct?

62 If the dinosaurs hadn't died out, then the world – and our beloved pets – would look very different today.

Can we end animal testing?

73 Stem cell research, 3D printing and computer modelling are widely used in research. So could they be used to replace animal tests?



73



56

MORE FOR YOU

Don't forget that *BBC Focus* is also available on all major digital platforms. We have versions for Android, Kindle Fire and Kindle e-reader, as well as an iOS app for the iPad and iPhone.



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EYE OPENER

Peekaboo!

PADRE BURGOS,
PHILIPPINES

Watch your step... this stargazer fish is waiting for a meal. So-called because of the eyes on the tops of their heads, stargazers use their fins as shovels to burrow themselves into the sand, leaping out to ambush any prey that passes overhead.

"I spotted the fish during a night dive when my torchlight caught its eyes," says photographer Reinart van Meteren. "It was about 30cm long, probably waiting to ambush one of the smaller fish close by. I gently moved the water on top of it in order to uncover its face, and then I had a few seconds to take the shot before it buried itself back into the sand."

Stargazers use their large, upward-facing mouths to create a vacuum, sucking in their unsuspecting prey. Some species can also create electric shocks of up to 50V, thanks to a specialised organ located behind their eyes – handy for warding off potential predators or confusing a potential snack.

PHOTO: REINART VAN METEREN



REPLY

Your opinions on science, technology and *BBC Focus*

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MESSAGE OF THE MONTH

Mining for good

Speaking as someone who has been involved in cryptocurrencies for some years, I was pleasantly surprised by your article in the January 2018 issue. Your report was well balanced, kudos.

However, there are more ways to become involved without necessarily investing money. While Bitcoin 'mining' is now industrial scale and beyond the reach of individuals, there are some cryptocurrencies directly connected with scientific/humanitarian endeavour that average people can use. Gridcoin (gridcoin.science) lets you 'mine' Gridcoins by allowing scientists to use your home computer to process data for research projects. Research ranges from cures for childhood cancers, to mapping the Milky Way in 3D, running particle collision data at the LHC and much more. The more research you do, the more Gridcoins you get. FoldingCoin and Curecoin are similar and do protein-folding work on the Folding@Home project. Meanwhile, readers with solar panels may wish to investigate SolarCoin. The SolarCoin Foundation issues a SolarCoin for each 1MWh of verified solar energy produced. The aim is to incentivise the transition to clean energy. The list goes on: Einsteinium aims to raise money for research grants; Pinkcoin is based on generating money for charities. Readers should be wary of scams and check a cryptocurrency's authenticity (including those I have mentioned) – any promises of huge investment returns is an immediate warning sign. Keep an eye on the HMRC guidance in relation to taxes, and seek professional advice if uncertain.
Steve, via email

➔ These are all worthy options, which then let you trade the currencies you earn for other cryptocurrencies. As Steve says, always exercise caution when trading money. – Ed

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a stylish **Kitsound Voice One speaker**. This smart speaker has room-filling stereo sound, built-in Amazon Alexa, a splash-resistant coating and multiroom technology – connect up to eight together to wirelessly to fill your home with epic sound. kitsound.co.uk



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SolarCoin is a cryptocurrency that rewards generation of solar energy

Raisin a drink

I commend Michael Mosley's effort to have a month free of alcohol, as described in his article in the January edition of *BBC Focus*. I was particularly interested in the small study quoted in the box on p48 in which those drinking the red wine with the alcohol removed appeared to do as well as those drinking the ordinary red wine, suggesting that it was not the alcohol but a constituent of the grapes that was producing the benefit. Grapes, and particularly raisins (dried grapes), have high levels of antioxidants and it would seem this was producing the reduction in blood pressure and C-reactive proteins. Rather than trying to justify the drinking of wine, it would seem better to have raisins rather than crisps and try not to drink alcohol (with all its other ill effects) at all.

Dr Roger Webber, Scotland

➔ The antioxidants in the grapes could be



a contributing factor, but in the study (bit.ly/2n45Hta) it seemed that alcoholic wine performed better than a non-alcoholic analogy, lending credence to the idea that a small portion of alcohol offers some benefit.

– Daniel Bennett, editor

Alphabet soup

In the January issue of *BBC Focus*, you look at how scientists have expanded the genetic alphabet. It left me wondering how is it that 64 RNA triplets (codons) can code for only 20 amino acids? There must be more possibilities, even though (as it happens) only 20 occur naturally!

Similarly, how can 216 synthetic codons code for only 172 amino acids? And how is 216 related to 64?

Simon Bartlett, via email

➔ Good question. First we must consider that codons are made of groups of three of the four different bases (nucleotides) joined together. This means we have a total of 4^3 , or 64, different combinations and so gives us the 64 different codons. So far, so good. However, in most cases the same amino acid can be made from several different codons, this of course limits the total

number of amino acids that can be coded. For example, arginine is formed from six different codons. Also, there are three so-called 'stop codons' that do not code for an amino acid but instead signal the end of the translation process and the end of the protein chain. The same case applies

in the synthetic example meaning only 172 amino acids can be produced despite there being 216 codons.

– Jason Goodyer, commissioning editor

Slow food

In the Christmas edition of *BBC Focus* (p80) you list the top 10 sleepest animals. Unfortunately, no explanations were given. We have three cats who seem to spend most days sleeping. This is, I believe, typical of the cat family. Discussing this with my wife, who has always owned cats, she suggests they need lots of sleep to recoup energy following strenuous hunting trips. However, though our cats are most active at night, their forays into the garden seem sporadic and hardly warranting the amount of sleep they get. In the wild, no doubt cats expend a lot of energy stalking prey unsuccessfully so that after a kill they need a good lie down. Or do they need long periods of sleep to allow their bodies time to digest their almost entirely meat diet? However, many of the animals on your list are vegetarians, so what's their excuse? Do they need lots of rest due to a low-energy diet, or are there other reasons?

Maurice, via email

➔ Cats are crepuscular animals, meaning they are naturally more active at dusk and

Do domestic cats need lots of sleep, or are they simply lazy, ponders Maurice

dawn. Sometimes they can also appear to be fast asleep when they're actually snoozing. They go into a light sleep, lying in wait for some prey to come by. Obviously, in domestic cats these behaviours are hangovers from their ancestors. The herbivores in our list typically eat food that is low in nutrients, so they lead a soporific lifestyle to avoid expending too much energy (we're looking at you koalas).

– **Daniel Bennett, editor**

A dense matter

I regret I could not fully understand Dr Alistair Gunn's answer to the question "How dense is the Universe?", which appeared in the January issue of *BBC Focus*. However, I remember from a lecture given by Astronomer Royal Dr Martin Rees some 20 years ago that he stated that the Universe has a density exactly the same as a sheet of paper, in this case 80gsm. Dr Martin Rees did not split the answer into visible or dark matter nor mention energy in this particular comment. This is the sort of picture I can readily equate with – surprising though that comment was.

Hally Hardie, Peterborough



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Tails of the unexpected

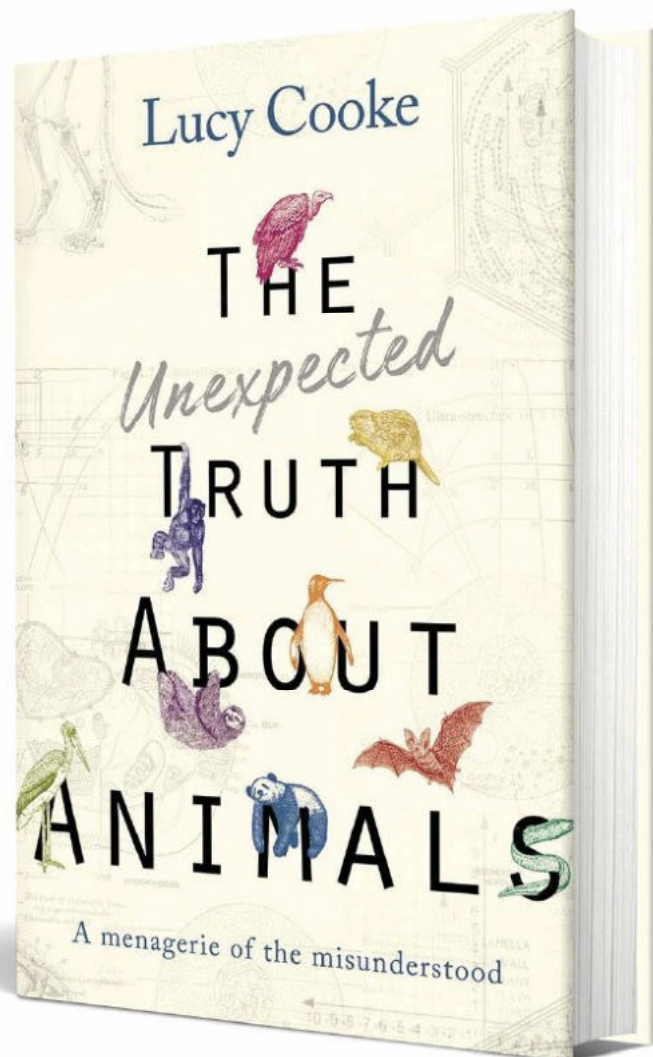
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FEBRUARY 2018

EDITED BY JASON GOODYER

BIOLOGY

MEET ZHONG ZHONG AND HUA HUA – THE WORLD'S FIRST MONKEYS CLONED THE SAME WAY AS DOLLY

Two genetically identical long-tailed macaque clones have been successfully bred by Chinese researchers

A pair of primate clones bred using somatic cell nuclear transfer (SCNT), the technique used to create Dolly the sheep more than 20 years ago, have been born at the Chinese Academy of Sciences in Shanghai.

The newborns are just several weeks old and have been named Zhong Zhong and Hua Hua after the Chinese adjective 'zhonghua', which means Chinese nation or people. They are



PHOTO: QIANG SUN/MU-MING POO/CHINESE ACADEMY OF SCIENCES



Ultrasound scans of surrogate uteruses from the SCNT process. The uterus on the left contains no foetus, but the one on the right has been successfully impregnated and the foetus can be seen

currently being bottle-fed and are developing normally compared to other monkeys their age.

In SCNT, the nucleus is removed from an egg cell and is replaced with a different nucleus from another cell. The egg cell then merges with the implanted nucleus and develops into a clone of whatever it was that donated the nucleus.

Previously, in sheep, mice and cows, adult donor cells have been used to create healthy clones. However, adult primate cells proved resistant to the technique. The Shanghai team overcame this by using donor cells taken from a macaque foetus.

While Zhong Zhong and Hua Hua are the first primates to be cloned using this technique, primates have been cloned in the past. In 1999, a rhesus macaque called Tetra became the first primate to be cloned, though this was achieved using a simpler method called embryo splitting. Here, the cells in the embryo are split after reaching the eight-cell stage to create four identical two-cell embryos in a manner similar to naturally occurring twins.

The breakthrough will make it possible to breed genetically uniform monkeys.

This will enable researchers to study primates in unprecedented detail, as well as help with the development of drugs and therapies for use in humans. "There are a lot of questions about primate biology that can be studied by having this additional model," said Prof Qiang Sun. "This will generate real models, not just for genetically based brain diseases, but also cancer, immune or metabolic disorders and allow us to test the efficacy of the drugs for these conditions before clinical use."

The researchers are eager to point out that they are following strict guidelines for animal research set by the US National Institutes of Health, and accept that the scientific community should debate acceptable laboratory practices concerning the cloning of non-human primates. "We are very aware that future research using non-human primates anywhere in the world depends on scientists following very strict ethical standards," explained co-author Prof Muming Poo.

They now plan to continue improving the technique and expect more macaque clones to be born over the coming months.

If you're interested in the debate around animal testing, turn to p73.

HOW DOES SCNT CLONING WORK?

A cell in an early embryo has something akin to a superpower. It can transform into any part of the organism, a skin cell perhaps, a muscle cell, a nerve cell or a blood cell. Before Dolly, everyone assumed that in mammals this process of specialisation, so-called 'differentiation', was irreversible. Dolly proved otherwise.

Scientists start with an egg cell ①. The nucleus (the part of the cell that contains the majority of the genetic material) is removed from the egg cell ②. A single differentiated cell is picked up by a tiny needle. In Dolly's case, the differentiated cell was an udder cell from an adult donor ③. The cell is injected into the egg cell and a small electrical pulse is used to fuse the nucleus into its new environment and to kick-start cell division ④. The egg cell and differentiated cell fuse. You can see in this image that the egg cell now has a nucleus (upper centre) ⑤. The embryo is implanted into the uterus of a surrogate female. She carries the clone to term ⑥.

PHOTOS: SCIENCE PHOTO LIBRARY/AS, GETTY

TIMELINE: ANIMALS WE'VE CLONED

1894



German biologist Hans Driesch takes a two-cell sea urchin from

the Bay of Naples and shakes it in beaker of water. The cells part, giving rise to two, independent but identical, sea urchins.

1902



Hans Spemann, another German scientist,

uses a fine hair from his baby son to split a salamander embryo in two. The result: two amphibians for the price of one.

1952



In the US, Robert Briggs and Thomas King perform a successful

nuclear transfer, by moving a nucleus from an embryonic frog cell into an egg cell whose own nucleus had been removed.

1962



Instead of using nuclei from frog embryos, Oxford biologist John Gurdon

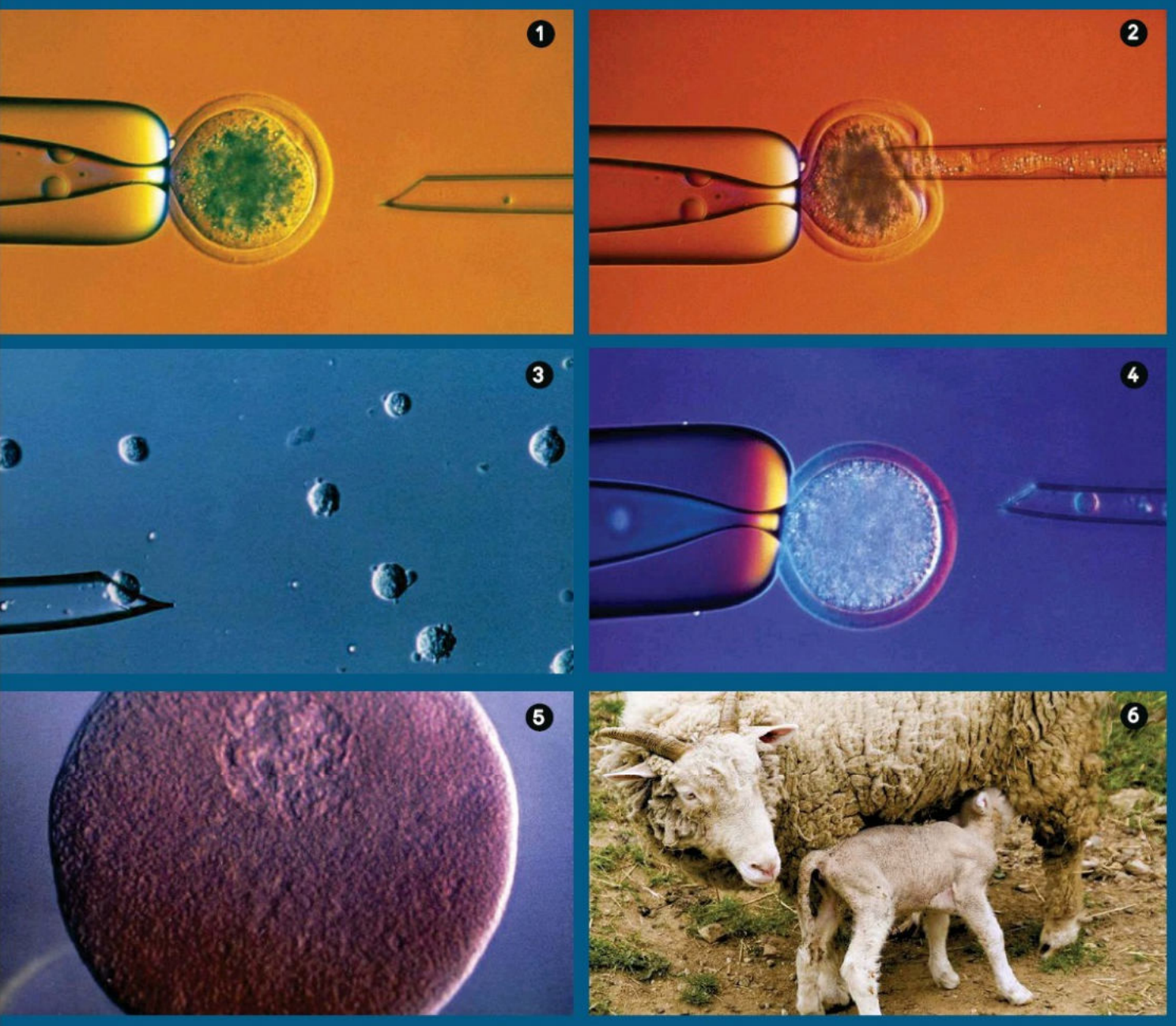
takes them from adults, demonstrating that a differentiated nucleus still has the power to build an entire animal.

1963



Chinese embryologist Tong Dizhou applies the same technique

to fish, though his work, originally published in his native Chinese, does not receive much attention beyond China.

**1996**

The cloning of Dolly the sheep builds on Gurdon's method, showing that the nucleus from a differentiated cell retains the ability to make an entire animal from scratch, even in mammals.

1999

A team led by Prof Gerald Schatten create Tetra, a rhesus macaque, using embryo splitting. Here, the cells in the embryo are split after reaching the eight-cell stage to create four identical two-cell embryos.

2001

Researchers at Texas A&M University create the first cloned pet, using a cell from a brown-and-white tabby cat called Rainbow to make 'CC' (aka 'Copy Cat' or 'Carbon Copy').

2001

Scientists at Advanced Cell Technology in the US are the first to clone an endangered species. Noah the gaur, a species of wild ox native to Asia, dies from dysentery after two days.

2005

Controversial South Korean scientist Hwang Woo-Suk uses the ear cell from an Afghan hound to make Snuppy, the world's first cloned dog. A Labrador acts as surrogate mother.

DINOSAURS

'RAINBOW DINOSAUR' MAY HAVE HAD GLITTERY FEATHERS

Just call it the disco dinosaur. *Caihong juji*, a newly discovered duck-sized dinosaur that lived around 160 million years ago in what is now China, had a vibrant rainbow crest and iridescent hummingbird-like plumage, a team of international researchers say.

The finding was made following the analysis of an immaculately preserved *C. juji* fossil – a name meaning 'rainbow with big crest' in Mandarin – first discovered by a farmer in northeastern China in 2014. The feathers on the fossil are so well preserved that the researchers were able to determine their minute colour-bearing structures.

"When you look at the fossil record, you normally only see hard parts like bone, but every once in a while, soft parts like feathers are preserved, and you get a glimpse into the past," said Chad Eliason, who took part in the research. "The preservation of this dinosaur is

incredible, we were really excited when we realised the level of detail we were able to see on the feathers."

By examining the feathers using powerful microscopes, the researchers were able to make out the imprints of melanosomes, which are the parts of cells that contain colour pigments. While there was very little of the pigment itself present, the shape of the melanosomes alone was enough for the scientists to determine the colour of the feathers. This is because melanosomes reflect light in different colours depending on their shape. It turns out that the pancake-shaped melanosomes in *C. juji* most closely match those of modern hummingbirds.

Colourful plumage is frequently used by birds to attract mates, so the rainbow feathers of *C. juji* may well have been a prehistoric version of a peacock's iridescent tail, the researchers say.

ABOVE: The shimmering, multicoloured feathers on the rainbow dinosaur may have been used to attract a mate



SPACE

EERIE BLUE SPACE ROCKS CONTAIN INGREDIENTS VITAL FOR LIFE

IN NUMBERS

130

The average sound level, in decibels, of a rooster's crow. This is equivalent to a jet taking off at a distance of 15 metres. X-ray images have shown that roosters appear to have special flaps in their ears that partially close off the ear canals when they crow, to protect their hearing.

23, 249, 425

The number of digits belonging to the largest prime number ever discovered. It was found on Boxing Day by the Great Internet Messene Prime Search – an international collaboration searching for the largest numbers that are divisible only by themselves and one.

347

The length, in km, of an underwater cave found on the Yucatan Peninsula on the eastern coast of Mexico – the longest ever discovered.

Tiny crystals found embedded in two meteorites contain water and complex organic compounds – ingredients essential for the development of life.

The crystal fragments were painstakingly extracted from two different meteorites, named Monahans and Zag, that have been stored at NASA's Johnson Space Center in Texas since they landed in 1998. Monahans smashed into the ground in Texas in March that year, while Zag plunged to Earth near Morocco in the August.

Cutting-edge X-ray scans of the crystals showed them to contain a range of organic chemical components including carbon, oxygen and nitrogen, as well as amino acids needed to form proteins. They also carried microscopic traces of water believed to date back to the infancy of the Solar System about 4.5 billion years ago.

"This is really the first time we have found abundant organic matter also

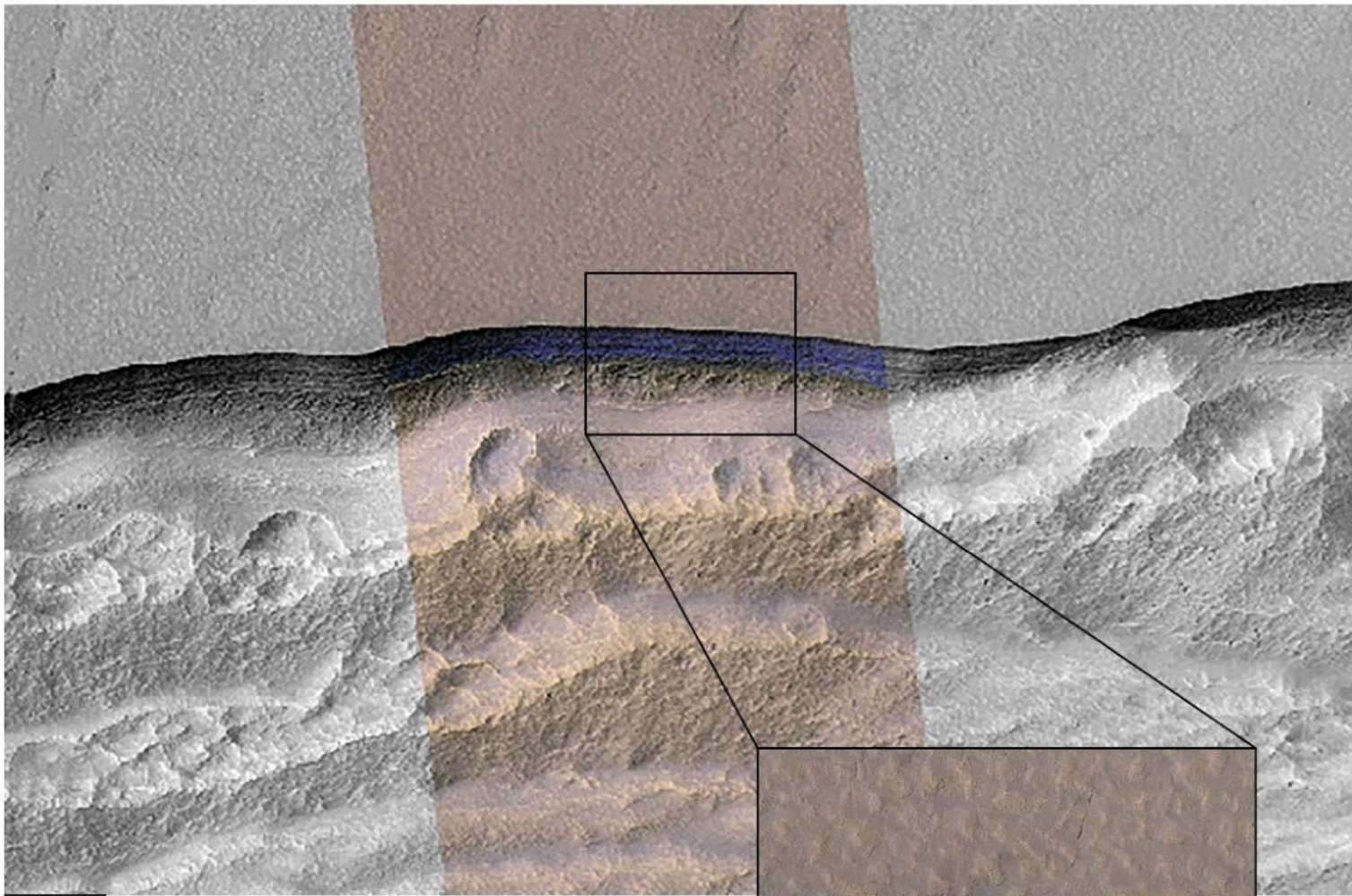
associated with liquid water that is really crucial to the origin of life and the origin of complex organic compounds in space," said the Open University's Dr Queenie Chan. "We're looking at the organic ingredients that can lead to the origin of life."

A detailed study of the chemistry of the tiny blue and purple crystals suggests they may have originally been seeded by volcanic activity on Ceres, which is a brown dwarf planet that is the largest object in the asteroid belt between the orbits of Mars and Jupiter.

"Things are not as simple as we thought they were," Chan said. "Everything leads to the conclusion that the origin of life is really possible elsewhere. There is a great range of organic compounds within these meteorites, including very primitive type of organics that likely represent the early Solar System's organic composition."

This blue crystal, which contains water and compounds essential for life, was found within the Zag meteorite





SPACE

HUGE SLABS OF ICE DETECTED BENEATH THE SURFACE OF MARS COULD SUSTAIN HUMAN COLONY

One of the many problems standing in the way of humans establishing a colony on the Red Planet is obtaining a supply of fresh drinking water. Now, researchers using NASA's Mars Reconnaissance Orbiter (MRO) may have found a solution: there are at least eight sites where thick deposits of ice buried beneath the planet's surface are exposed in faces of eroding slopes. The team located the sites using the High-Resolution Imaging Science Experiment (HiRISE) camera on the MRO. The ice was likely deposited as snow long ago and is thought to consist of relatively pure water ice.

It was known from previous missions that around a third of the surface of Mars contains shallow ground ice as well as thicker deposits

at the poles. However, the new findings show cliffs of ice more than 100m thick in detail.

"The finding gives us surprising windows where we can see right into these thick underground sheets of ice," said Shane Byrne, who co-authored the report. "It's like having one of those ant farms where you can see through the glass on the side to learn about what's usually hidden beneath the ground. Astronauts could essentially just go there with a bucket and a shovel and get all the water they need."

Other than providing potential colonisers with a supply of drinking water, the discovery may help us learn more about the long-term patterns in Mars's climate that led to the ice's formations.

Underground ice exposed at one of Mars's steep slopes appears here as a bright blue band

BIOLOGY

FUNCTIONING HUMAN MUSCLE GROWN FROM STEM CELLS

Forget hitting the gym, this is a much more efficient way of building muscle: a team at Duke University has grown functioning human skeletal muscle using induced pluripotent stem cells. The researchers say that this breakthrough could help them treat diseases such as muscular dystrophy.

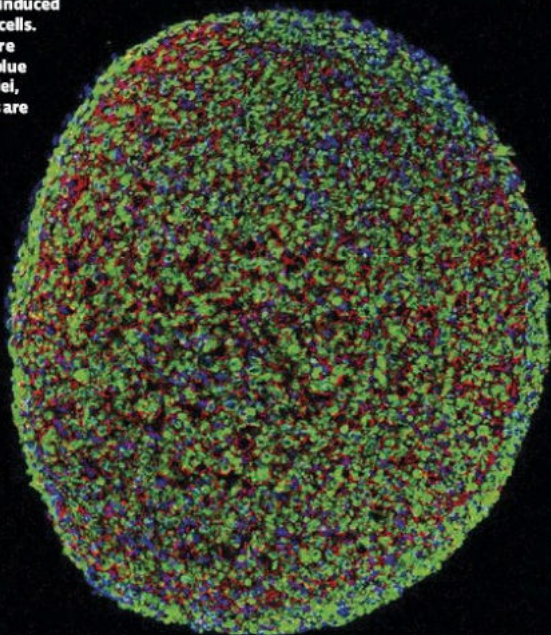
The muscles were grown using pluripotent stem cells. These are cells taken from adult non-muscle tissues, such as skin or blood, and reprogrammed to revert to a nascent state. These stem cells were grown into muscle tissue by flooding them with a molecule called Pax7 – a key component in the formation of muscle tissue.

The team then grew the cells in a 3D scaffold, encouraging them to form muscle fibres that could

contract and respond to external stimuli, just like living muscle. The team then transplanted the muscle into mice, where it began to integrate into the existing tissue. It was not as strong as naturally grown muscle, but still holds promise for treating degenerative muscle diseases.

“The prospect of studying rare diseases is especially exciting for us,” said Prof Nenad Bursac. “When a child’s muscles are already withering away from something like Duchenne muscular dystrophy, it would not be ethical to take muscle samples from them and do further damage. But with this technique, we can just take a small sample of non-muscle tissue, like skin or blood, revert the obtained cells to a pluripotent state, and eventually grow an endless amount of functioning muscle fibres to test.”

Cross-section of muscle fibre grown from induced pluripotent stem cells. The green areas are muscle cells, the blue areas are cell nuclei, and the red areas are the surrounding support matrix



THE FOUL-MOUTHED

Holy & #\$\$% A team at Maastricht University has found Facebook users who are more prone to using profane language often post more trustworthy content, especially when expressing negative emotions such as anger, exasperation or fear.

MALE CYCLISTS

Think cycling makes men impotent? On yer bike! A team at the University of California has found that cycling has no greater impact on male sexual and urinary health than running or swimming.

GOOD MONTH

BAD MONTH

MICROWAVE COOKS

Having a ready meal habit may be just as bad for the environment as it is for your waistline. A study by the University of Manchester has found that the yearly CO₂ emissions from just 19 microwaves are comparable to those of a family car.

CRIMINALS

Bad luck, bad guys! A statistical analysis carried out by psychologists at Johannes Gutenberg in Germany has determined that the so-called ‘CSI effect’, which was once thought to help criminals find out how to conceal their crimes by watching TV crime shows, is a myth.



"If you had these plants on a wall, you would contribute to ambient lighting"

Chemists are engineering organisms without genetic modification by adding tiny, nanoscopic parts. Prof Michael Strano of MIT reveals how he used 'nanobionics' to create glowing plants

Why add bionic parts to plants?

Plants have a number of properties we don't encounter in synthetic materials: plants self-repair, they're easy to recycle, they're low-cost. But importantly, they harvest energy from the Sun via photosynthesis, then store that energy in the form of sugars and starches. So you can think of a plant as a combination of solar cell and

battery. Plant 'nanobionics' seeks to work out the ways that you could transform a living plant and use these capabilities. We're using small nanoparticles that can enter the plant and interact with biochemical pathways to give it new functions.

How did you make glowing plants?

A light-emitting plant uses three different kinds of nanoparticles. We put them into the plant through pores on the surface of the leaf. The reason why we need three

nanoparticles is pretty technical, but basically they have the net effect of taking some of the plant's stored energy and converting it into green light. One of the particles has an enzyme called luciferase, which is the one that allows fireflies to glow. We've started working on an on/off switch to have the plant emit light when it's dark but then, when there's incident sunlight, turn off and just recharge.

How much light do they produce?

The plants glow for about 3.5 hours. The brightness is easily visible with the naked eye. We looked at kale, watercress and spinach. We do a brightness test with a 10cm watercress or arugula [rocket] plant, and they currently give out about a thousandth of the amount of light needed to read by – but that's a really high illumination standard. The amount of light we generate now is actually enough for what architects call 'indirect lighting', so if you had a bunch of these plants lined up along a wall, you would contribute to ambient lighting.

What are the advantages of nanobionics?

We don't have to make a new organism, we can go

BELOW: Prof Michael Strano from MIT





ABOVE: Two nanobionic watercress plants illuminating the pages of a book

up to an existing plant and modify it. Our modification stays with that plant – there's no danger in uncontrollably reproducing these traits throughout the environment, which are concerns that are sometimes raised with genetically-engineered plants. Seven per cent of all energy usage is from lighting, so even if we could make a modest dent in that usage, it would have an impact in terms of carbon dioxide release. Another reason is they're beautiful. I think they're going to form an important contribution to our aesthetic environment. For the next three years, we're going to study how to make a plant brighter, and how to use it in architecture.

What else could bionic plants do?

We have a lot of ideas, some are pretty crazy. Last year we published a study on a chemical-sensing plant: it measures chemicals in its environment then sends an infrared signal to your phone. We demonstrated that it can measure explosives in groundwater. This idea of a 'sentinel plant' is gaining traction. Modifying the operation of plants using nanoparticles is not just speculative, we think they're going to be widely used in plant engineering in agriculture.

THEY DID WHAT?!



'SWEATING' ROBOT CREATED

What did they do?

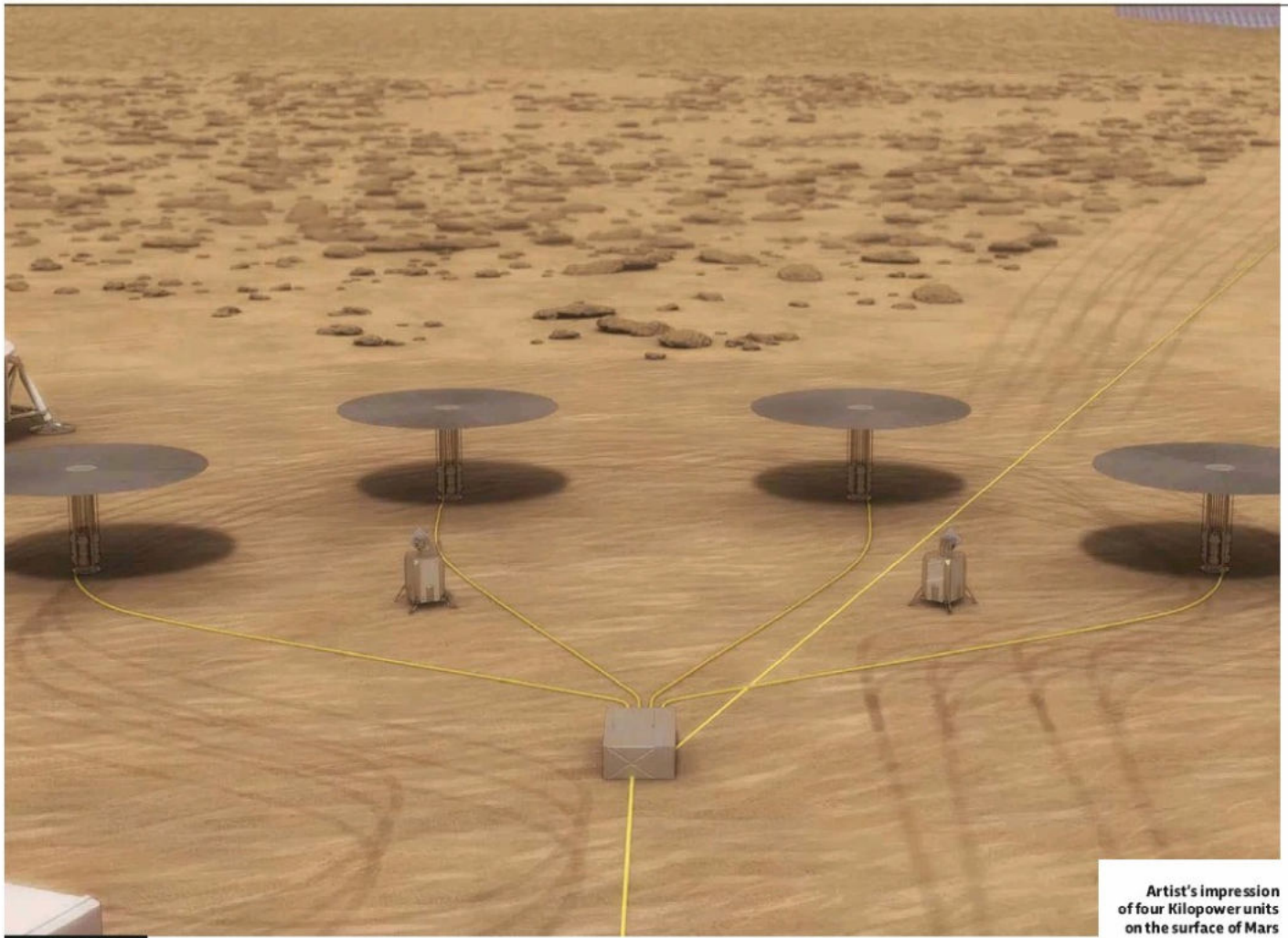
A team of researchers at the University of Tokyo have created Kengoro, a humanoid robot that 'sweats' to cool itself down when completing a workout consisting of push-ups, sit-ups and pull-ups.

Why did they do that?

The robot is designed to have anatomically correct musculoskeletal structures closely resembling those of humans. However, the researchers initially had difficulty in preventing Kengoro's complex machinery from overheating when performing complex actions. The solution was to punch a network of tiny holes in the robot's frame and use it to carry water around the various structures. As the robot heats up, the water evaporates, cooling it down in much the same way as sweat cools down humans.

What could it be used for?

So far, Kengoro can perform around 100 different types of subtle movement – around a quarter of what a human is capable of, if you discount facial muscles. Even so, the research has many possible future applications, including the design of better crash dummies and more efficient prosthetics.



Artist's impression of four Kilopower units on the surface of Mars

SPACE

NASA'S COMPACT NUCLEAR REACTORS COULD POWER COLONIES ON MARS

If humans are ever to build colonies on the Moon or on Mars, we are going to need a reliable way of powering essentials such as lighting, water and oxygen supply – not to mention a means of producing fuel for the long schlep home.

Enter Kilopower, NASA's pioneering compact nuclear fission reactor currently being put through its paces at the space agency's Nevada National Security Site (NNSS).

The prototype power system was designed and developed by NASA's Glenn Research Center in collaboration with NASA's Marshall Space Flight Center and the Los Alamos National Laboratory.

It is hoped that the power system could provide up to 10 kilowatts of electrical power – enough to run two average households – continuously for at least 10 years. Just four Kilopower units would provide sufficient power to establish an outpost, the team says.

“ON THE MOON, KILOPOWER COULD BE DEPLOYED TO HELP SEARCH FOR RESOURCES”

The team has chosen to work on fission power due to the challenging conditions that must be endured if a space colony is to be successfully built. On Mars, the Sun's power varies widely throughout the seasons, and on the Moon, the cold lunar night lingers for 14 days – ruling out the option of solar power.

“We want a power source that can handle extreme environments,” said Lee Mason, NASA's principal technologist for power and energy storage. “Kilopower opens up the full surface of Mars, including the northern latitudes where water may reside. On the Moon, Kilopower could be deployed to help search for resources in permanently shadowed craters.”

Kilopower tests recently began at the NNSS and will conclude with a full-power test lasting approximately 28 hours towards the end of March this year.

THINGS WE LEARNED THIS MONTH

TEA BOOSTS CREATIVITY

Want to get your creative juices flowing? Have a cuppa. A team at Peking University has found that students performed better in creativity tests after drinking a cup of regular black tea. Put a brew on!

IT'S MUCH EASIER TO CATCH FLU THAN WE THOUGHT

We all know it's best to steer clear of a friend who is coughing and spluttering in the midst of flu season. However, a team at the University of Maryland has found that infectious particles can be spread simply by breathing.

ADOLESCENCE NOW LASTS UNTIL 24

According to research carried out at the Royal Children's Hospital in Melbourne, Australia, the recognised age at which adolescence ends should be raised to 24 – up from 19. The study concludes that people are staying in education longer and getting married later, and there is evidence that some people continue growing into their 20s.

OUR NOSES GO COLD WHEN WE THINK TOO HARD

A team at the University of Nottingham has found that our schnozzles drop in temperature when we face a complex mental task. The effect is thought to be due to the body diverting blood from the extremities to help out hardworking neurons.

ENGINEERING

ACOUSTIC TRACTOR BEAM BREAKTHROUGH COULD LEAD TO LEVITATING HUMANS

Here's an idea that is really gaining traction: for the first time, University of Bristol engineers have created an acoustic tractor beam capable of trapping objects larger than the wavelength of the sound being used.

This discovery could lead to technology capable of manoeuvring drug capsules around the body, container-less transportation systems, and even the levitation of humans for medical or other purposes, the engineers say.

Researchers previously thought that acoustic tractor beams were limited to levitating small objects. This is because previous attempts to trap particles larger than the wavelength of the sound being used were unstable, with levitated objects spinning out of control.

The team found a workaround for this problem by using rapidly fluctuating tornadoes of sound – essentially a twister-like structure

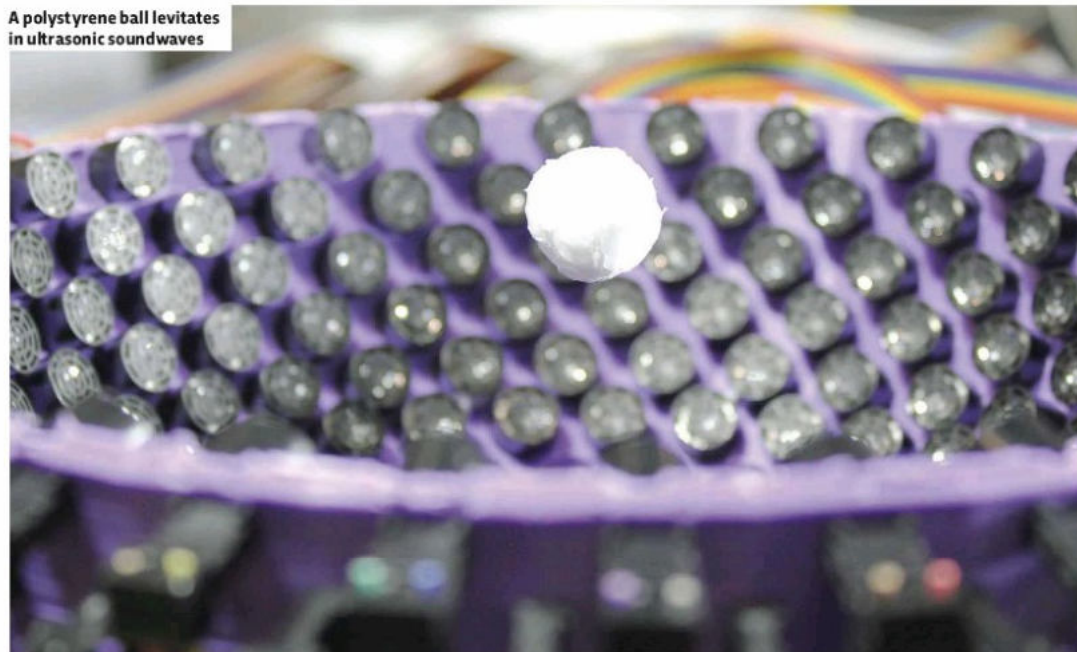
made up of a loud sound surrounding a silent core. They were then able to increase the size of the silent core, allowing it to hold larger objects.

Using ultrasonic waves at a pitch of 40kHz, a frequency above human hearing but detectable by dogs, the researchers held a two-centimetre polystyrene sphere stationary in the tractor beam. The sphere was more than two acoustic wavelengths in size, making it the largest object to be trapped in a tractor beam.

The finding gives hope that larger objects, such as humans, could be levitated using the same technique, the researchers say.

"Acoustic tractor beams have huge potential in many applications," said Prof Bruce Drinkwater, who supervised the research. "I'm particularly excited by the idea of contactless production lines where delicate objects are assembled without touching them."

A polystyrene ball levitates in ultrasonic soundwaves



MICHAEL MOSLEY ON... **THE MICROBIOME****"IF YOU BEFRIEND YOUR GUT BACTERIA, COULD YOU HELP YOUR IMMUNE SYSTEM TO THRIVE?"**

One of the hottest topics in 2017 was the microbiome, and I'm predicting that gut microbes will

continue to stir the emotions of scientists and consumers in 2018.

For those who are not familiar with the more intimate content of your bowels, the gut microbiome is a term that covers the one to two kilograms of assorted microbes that live in your guts and are essential to your health. There are at least 1,000 different species down there, made up of trillions of different cells.

Although that is a big number, in the past it was wildly exaggerated. We are not '90 per cent bacteria' and '10 per cent human', as many books and articles have claimed, but more like 50:50. In fact, one researcher who helped explode that particular myth claimed the proportions are so similar that "each defecation event may flip the ratio to favour human cells over bacteria".

As a medical student, I was taught that the main role of our gut microbes was to protect us from dangerous invaders and synthesise a few vitamins. Now we know they do far more than that. Among other things (like influencing our mood and weight), those little microbes help regulate our entire immune system. Big claims? Certainly.

Over the last half-century we have seen a massive rise in allergic diseases, such as asthma and eczema, caused by an overactive immune system. We have also seen a surge in autoimmune diseases, ranging from inflammatory bowel disease (IBD) to type 1 diabetes, which are primarily caused by an immune system that has got out of control. One of the reasons for this rise seems to be that over time we have laid waste to a particular population of microbes



that live in the gut and are known to immunologists as the 'Old Friends'. They've been given that name because they have evolved with us over millions of years, and are vital for our health. Without enough of your Old Friends around, so the theory goes, your immune system behaves like a drunken teenager, smashing up its own home. A recent study, for example, found that one of the Old Friends, a gut bacteria called *Bacteroides*, helps prevent IBD by recruiting white blood cells to kill a cell of the immune system that can trigger IBD.

So why did it all go wrong? What has happened to the Old Friends? Well, a diet of antibiotics and junk food hasn't been good for their long term health. We also know that children who are born by Caesarean section (which is increasingly common) are far more likely to develop allergic diseases later in life, possibly because they are less likely than those born vaginally to inherit their mother's Old Friends.

The good news is that it's never too late to try and give your Old Friends a bit of a boost. I am now a big fan of home-made fermented foods like sauerkraut, which are rich in living bacteria. I have also switched to a diet that has more of the foods that will help my microbiome thrive (mainly those that contain plenty of fermentable fibres).

I'm also steering clear of the prebiotics, probiotics and supplements that are sold in the shops. From what I've learnt, few have credible science behind them and most of what is sold is based on hype. That may change, though. Watch this space. **E**

Dr Michael Mosley is a science writer and broadcaster, who presents *Trust Me, I'm A Doctor* on BBC Two. His latest book is *The Clever Guts Diet* (£8.99, Short Books).

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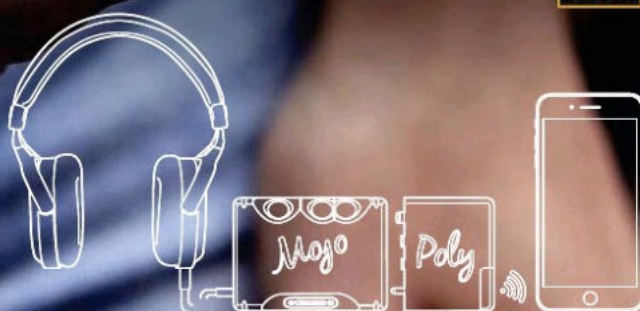


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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

CES REPORT 2018

FEBRUARY 2018

EDITED BY RUSSELL DEEKS

A LEAP INTO THE FUTURE

After years of hints and speculation, mixed reality start-up Magic Leap (valued at close to \$2bn) finally unveiled its first headset at the recent Consumer Electronics Show (CES) in Las Vegas.

The Magic Leap One system consists of a pair of goggles, a miniaturised, belt-worn PC and a handheld controller. Its creators say the device makes use of lightfield technology, which records a map of how light reaches a camera lens. With this information, the Magic Leap team says it can convincingly mix the virtual with the real. For example, while wearing the specs, animated characters could spring out of your kid's storybook, or a PC display could load up on your fridge door. There's still no word as to a commercial release, but developer kits are expected to start shipping early this year, so it can't be too far off.

There were plenty of other virtual reality and mixed reality headsets at CES, including the Vive Pro from HTC (with a much higher-res display than the existing Vive); the eye-tracking, EEG-equipped Looxid VR; the affordable, fold-out Aryzon; the Alexa-enabled Vuzix system; and the X1 headset from Third Eye. Depending how cynical you are, this either means that human communication and interaction is about to be disrupted like never before, or that *Pokémon Go* is about to get a bit more convincing...





BY SAMSUNG

Samsung's 'The Wall': not good for tiny apartments

MY SCREEN'S BIGGEST...

If there was one obvious 'theme' at this year's CES, it was really, really big screens. Garnering most of the headlines was Samsung's aptly-named The Wall: a 146-inch 4K TV made up of self-emitting MicroLEDs, as used in Samsung cinema screens. But LG wasn't far behind, touting both a 4K tower projector (the HU80KA) that'll throw a 150-inch screen onto any available surface, and a 65-inch OLED screen that can be rolled up like a newspaper. Nvidia got in on the 'bigger is better' action too, with a 65-inch, 4K 'big format gaming display' – basically a huge PC monitor with Nvidia Shield streaming capabilities built-in.

There was no word regarding pricing or availability for any of the above, but we don't foresee them being cheap. Sony was showing off a 120-inch projector that can be yours in the spring for a mere £22,000, but back in the real world, CES visitors could check out plenty of new 4K sets with HDR screens and/or built-in digital assistants (Bixby in Samsung's case, Google Assistant in LG's). Ever keen to stay one step ahead, Samsung was showing off 8K televisions that should be available before the end of the year...



LG's roll-up OLED screen



LG's new projector sends a 150-inch image onto any surface

What's 8K all about, then?

Less than 30 per cent of televisions sold worldwide in 2017 featured 4K displays, and 4K broadcasts are still few and far between. But that isn't stopping manufacturers pushing the next step: 8K.

The 8K standard refers to screens with a resolution of 7,680 × 4,320 pixels. That's four times the pixel count of a 4K screen, or 16 times that of a Full HD (1080p) TV. 8K is the highest resolution available on any current TV set, though 8K models are quite thin on the ground, and likely to remain prohibitively expensive for the foreseeable future.

The technology is proving popular with film-makers, though – partly because if you shoot in 8K then crop-and-zoom to 4K, the camera operator needn't get so close to the subject. Which is handy if you're filming tornadoes, or lions...



SIX OF THE BEST... PORTABLE COMPUTERS

CES 2018 was awash with new laptops, tablets and hybrids – here are some of the most interesting

1 BUSINESS BOOK

X1 Carbon is the cheapest of Lenovo's three new Thinkpads. Like the rest of the range, it features an onboard e-SIM so it's always connected, a Dolby Vision HDR display and a privacy shutter for the webcam. It also has 16GB of RAM and up to 1TB of SSD storage.

\$1,790 (£1,245 approx), lenovo.com

2 RAZOR SHARP

Razer's concept laptop is not a laptop at all. Instead, it's a laptop-shaped dock for the Razer Phone that sports a 13.3-inch HD screen, a keyboard and 200GB of storage. Processing is handled by the phone, which slots below the keyboard and doubles as a trackpad and a second screen.

ETBC, razer.com

3 FEELING ZEN

It may tip the scales at just 985g, but the Asus ZenBook 13 is no lightweight. It packs an Intel Core i7 CPU, an Nvidia GeForce MX150 GPU, 16GB of RAM, 1TB of SSD storage and a 4K UHD touchscreen. Plus, Harman Kardon speakers make it the perfect choice for music lovers.

ETBC, asus.com

4 CHEAP AND CHEERFUL

With just 4GB of memory and 32GB of storage, the latest addition to Acer's Chromebook range might not be suitable for power users. But it does offer 10 hours of battery life for just £249, and will run Android apps – making it a decent choice for students when it lands in April.

£249, acer.com

5 MAKE A NOTE

Samsung's new hybrid, the Notebook 9 Pen, features a 13.1-inch 1080p display, 16GB of RAM, an Intel Core i7 GPU and up to 512GB of SSD storage. It has an S-Pen stylus, which is great for arty types: think of it as a halfway house between the Galaxy Note 8 and a laptop.

ETBC, samsung.com

6 WATCH OUT, APPLE

HP's Spectre X360 15 laptop/tablet now packs in Intel's eighth-generation quad-core chipset and a Radeon RX Vega GPU, making this a powerful beast for those who want a rival to the MacBook Pro. Other additions include a number pad and a fingerprint sensor for security.

From £1,599 approx, hp.com

HOME IMPROVEMENTS

Not long ago, 'internet fridges' were a standing joke in tech circles. But improvements in Internet of Things (IoT) technology, coupled with the unstoppable rise of digital assistants like Siri, Alexa and Google Assistant have changed that, and CES 2018 was replete with all manner of devices designed to help us live smarter.

These included – yes – an Alexa-enabled fridge from LG (the InstaView ThinQ, with its 29-inch touchscreen display) and a Bixby-enabled one from Samsung (the Family Hub 3.0). But they also included the Toshiba Symbio, a combined speaker, security camera and home hub running Alexa; GE's

Kitchen Hub, a range hood with a built-in 27-inch display and camera; voice-activated ceiling lights (also from GE); a Philips 24-inch 7703 Android TV, which is designed for use in the kitchen and has Google Assistant onboard; and perhaps most intriguingly the MyLiFi lamp, which offers a fast, secure, wireless internet connection that uses light instead of radio waves.

As with all things IoT, the usual caveats about privacy and security apply. But there can be little doubt that domestic bliss is in the process of getting considerably more high-tech.



MyLiFi lamp

Toshiba Symbio

GE's voice-activated ceiling lights

Samsung's Family Hub 3.0

Google plastered its 'Hey Google' phrase all over Las Vegas, to advertise its voice assistant



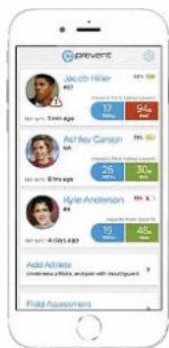
DIGITAL ASSISTANTS GO HEAD-TO-HEAD

Amazon's Alexa is leading the digital assistant race right now, but there's no guarantee it'll emerge as a final winner. As the hardware on show at CES revealed, Google Assistant is making serious inroads, and you can expect to see Google Assistant-powered speakers from the likes of Bang & Olufsen, JBL and Altec Lansing arriving in stores this year, as well as Google Assistant-powered tablets, smartphones, TVs, washing machines and more.

Google isn't hiding its intentions under a bushel, either: visitors to CES were greeted by a giant, voice-activated Google gumball machine that dished out prizes, while the city's monorail was given a Google makeover for the event.

STAYING ALIVE

Health and fitness heading your way in 2018



SMASHMOUTH

With concern growing about the dangers of concussion in contact sports, particularly for kids, Prevent Biometrics has come up with this Head Impact Monitoring System mouthguard. Four accelerometers measure the force, location and direction of all head impacts, and notify sideline personnel if there's any cause for concern.

From \$199 (£145 approx), preventbiometrics.com



DR DUCK

This is a children's robot companion with a difference. Built by meditech R&D outfit Sproutel for health insurers Aflac, My Special Duck is a therapeutic aid for kids with cancer. As well as music and games, it features a 'catheter' port so that youngsters undergoing chemotherapy can re-enact it with their fluffy friend, to help them feel less scared by the process.

EN/A, sproutel.com



BABY MAKER

This Mira fertility monitor from San Francisco's Quanovate Inc pairs with a smartphone app and – rather than just telling a woman if she's ovulating or not – uses AI to track and analyse her fertility over time, and hence predict in advance when she's most likely to be able to conceive.

ETBC, miracare.com



SUITED AND BOOTED

Designed for builders, agricultural labourers, rescue workers and so on, this connected insole pairs with an app and will alert supervisors if someone has a fall. It will also allow workers to monitor their posture and fatigue, and count their steps. Sadly, though, for now it's only available on a wholesale basis to makers of safety footwear.

\$149 (£108 approx), hortech.com



HANDY GADGET

We've covered plenty of advances in prosthetics in *BBC Focus* – but what if your hand is simply paralysed, rather than missing? Enter the Neomano robotic glove, which is expected to launch on Kickstarter later this year. It can help patients with spinal cord injuries carry out tasks like opening doors, picking up a glass or brushing their teeth.

ETBC, neofect.com

SUN SMART

Worried about your exposure to ultraviolet rays? This tiny sensor from L'Oréal, due to launch in the summer, sits discreetly on your thumbnail. It uses an NFC connection to relay data on your UV exposure to an Android/iOS app, warning you when it's time to get out of the sunshine.

ETBC, loreal-paris.co.uk



BEST OF THE REST

Coming soon to a shop near you...

1



2



3



4



5



6



1 COOL RUNNING

Forerunner 645 Music is the latest addition to Garmin's smartwatch range. It can store up to 500 songs, so runners can listen to music without needing to take their phone out with them. It also does the usual fitness tracking stuff, and there's Garmin Pay onboard for making contactless payments, too.

£400, garmin.com

2 SMART ART

The da Vinci 3D Pen Cool is the new model of the company's 3D-printing pen. Now, the resulting models aren't as hot to the touch. It's one of several new 3D-printing products from the company: there's also the tiny Nano printer and, for business users, the \$4,000 full-colour 3D/inkjet printer AiO.

\$45 (£33 approx), xyzprinting.com

3 DINKY DRONE

Is it a wasp? Is it a bird? No, it's a microdrone! Uvify Oori fits in the palm of your hand, but can roar along at speeds of over 80km/h (50mph). Its front-mounted camera streams first-person footage back to the full colour screen on the bundled handheld controller, or to any compatible pair of video goggles.

\$389 (£282 approx), uvify.com

4 TUNE TRACKER

You'll struggle to lose these SoundSport wireless headphones from Bose. As well as a neckband and over-ear loops, the Bluetooth in-ears have Tile's tracking tech built in, so if you do misplace them, just fire up the Tile app on your phone and it'll give you their last location.

£149, bose.co.uk

5 BYE BYE, POWERPOINT

Want to jazz up your business presentations? Perhaps it'd be worth investing in Samsung Flip, a 55-inch, 4K electronic whiteboard that connects to digital devices either wirelessly or via USB, then lets up to four users write, scribble or draw over the top. The board can be used in either landscape or portrait.

ETBC, samsung.com

6 BOTTOMS UP

It's important to let red wine breathe, but the wait between opening and pouring can be frustrating. This rapid aerator, from French company Aveine, will provide up to 24 hours of 'breathing' instantly. Plus, if you scan the label on your wine, the accompanying app will tell you its optimum breathing time. Cheers!

\$200 (£145), aveine.paris



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BBF57

Red alert for the Sumatran tiger. Fauna & Flora International seeks action in response to severe threat from poachers. 5 March deadline.

Photo: Brian McKay



This Critically Endangered tiger has been pushed to the edge of extinction – 350 or fewer remain. Give to stop the poachers at www.FFIsumatrantiger.org

Latest figures just released show 350 Sumatran tigers remain - down from 500. The figures, from the Sumatran Ministry of Forestry, show how the ruthless assault from poachers is pushing this magnificent creature right to the edge of extinction.

Fauna & Flora International (FFI) has put out an urgent call to the global community to save the last Sumatran tigers currently existing in the wild – and specifically to employ more rangers.

FFI is urgently seeking funds to step up their crucial conservation programme in Kerinci Seblat National Park, Sumatra, Indonesia. In order to safeguard the future existence of these magnificent creatures, it is vital that more rangers are employed.

Right now, the Sumatran tiger faces a number of very serious threats, which are putting their very survival in jeopardy. And, sadly, they are all man-made.

Poaching activity has reached unprecedented levels. Hunters make good money from the tiger's beautiful skin and demand is constantly growing. FFI's investigations show that there is a huge demand for tiger bone, which is used in traditional Asian medicines, and black market prices make this grisly trade all too profitable.

These grave threats have been exacerbated by a very serious loss of habitat. In the last ten to 15 years, natural forest cover in Sumatra has been slashed by almost a staggering 40%.

With such a dramatic loss of habitat, these majestic forest dwellers are struggling to survive and have been designated as Critically Endangered on the IUCN Red List, making the Sumatran tiger one of the most endangered tiger subspecies on the planet. This is a rating reserved for animals that face an extremely high risk of extinction in the wild.

Latest surveys have indicated that there may now be as few as 350 Sumatran tigers existing in the wild. Thanks to the vital work of FFI's Tiger Protection and Conservation Programme, the numbers have stabilised in the Kerinci Seblat National Park, but the species is still under severe threat.

The illegal poaching syndicates are ruthless and will stop at nothing to supply the market. Other poachers are also in the area, sabotaging FFI's conservation work. In 2016, bird poachers vandalised 16 camera traps set by the tiger conservation team, which meant vital evidence was lost.

This is an ongoing battle, but it is one we must win. Debbie Martyr, FFI Team Leader of the Kerinci Tiger Project in Sumatra, says:

"Ranger teams walked almost 1,100 miles on forest patrols in and bordering the national park and destroyed more than 16 active tiger snares. That is why we need to step up patrol regimes".

Tiger populations are dreadfully fragile.

The signs suggest that FFI's approach is working, as patrols are reporting more evidence of tigers. Yet if FFI cannot recruit more rangers to protect the tigers against the increased efforts of the poachers, then all our good work could be undone.

350 Sumatran tigers remain - down from 500. Urgent support needed for action plan. We must act now to save them.

- £83,131 is needed to help us fund more rangers and step up action against the poachers in Kerinci Seblat National Park.
- This is one of the final strongholds of the incredibly rare Sumatran tiger.
- FFI's work here could be all that stands between the Sumatran tiger and extinction.

That's why it's absolutely vital that we increase our patrols to protect tigers from poachers – and work towards greater protection for their delicate habitat.

If we're going to save the Critically Endangered Sumatran tiger from complete extinction, it's crucial that we have the means to take action now.

FFI must raise £83,131. To do that, the charity is asking you to make an urgent contribution today.

Please send a gift, by no later than 5 March to help safeguard the future survival of the last few remaining wild Sumatran tigers.



Photo: Gill Shaw

"If you value the natural world – if you think it should be protected for its own sake as well as humanity's – then please support Fauna & Flora International."

Sir David Attenborough
Fauna & Flora International vice-president

Together, we can save the Sumatran tiger from extinction – but only if we take action immediately.

To take action for the Sumatran tiger please go to www.FFIsumatrantiger.org or cut the coupon.

If the coupon to the bottom right is missing, please send your cheque (payable to FFI) to: Freepost FAUNA & FLORA INTERNATIONAL by 5 March at the very latest.



Photo: Debbie Martyr/FFI

FFI is driving down wildlife crime, and in conjunction with local police, is successfully investigating and arresting wildlife criminals. Your support today can help stop the senseless killing of Sumatran tigers and their cubs.

Fauna & Flora International, founded in 1903, was the world's first international conservation organisation. Today its work spans the globe, with over 150 projects in more than 50 countries. It has a strong history of finding creative solutions to conservation problems and of working with local communities. FFI is supported by the most eminent scientists and members of the conservation movement.

Fauna & Flora International (FFI) has launched an emergency appeal, backed by Sir David Attenborough, to raise £83,131 to help save the Sumatran tiger.

These items are vital to help save the remaining Sumatran tigers from extinction.

£6,500 could buy a replacement 4WD jeep to transport rangers to distant patrol sites - our current vehicle has severe engine problems.

£3,000 could help get two extra rangers into the field to prevent poaching.

£400 could buy camping equipment or boots for 28 rangers.

£72 could buy first aid kits to treat injured rangers whilst out on patrol.

£32 could help buy charging units for telephones; essential to getting extra help if poachers are spotted.

Donations large or small will help us save the Critically Endangered Sumatran tiger from illegal poaching syndicates.

Cut the coupon below and return it to FFI, together with your gift, to help save the Critically Endangered Sumatran tiger. Alternatively, go to www.FFIsumatrantiger.org. Thank you.

I want to help save the remaining 350 Sumatran tigers today, with a donation of £

☐ I enclose a cheque payable to Fauna & Flora International
OR ☐ I wish to pay by credit/debit card

Card No:

Expiry Date: Security code:

Issue Number: (Master only)

Title Forename

Surname

Address

Postcode

Please email the latest updates, appeals and events to me at:

See the difference you have made

To show how your support has helped, we will keep you informed on the progress of this project and our other work around the world to protect endangered species by mail. We will also send you carefully selected projects where your support could make a difference. If you don't want this information please tick the box below.

☐ Please don't contact me by post
We keep your personal details secure and never sell, trade or rent them out.

See full details at www.fauna-flora.org/privacy

Please return to: Freepost FAUNA & FLORA INTERNATIONAL

The David Attenborough Building, Pembroke St, Cambridge CB2 3QZ
or go to www.FFIsumatrantiger.org to donate online now.

Please note: if Fauna & Flora International succeeds in raising more than £83,131 from this appeal, funds will be used wherever they are most needed. Registered Charity Number 1011102. Registered Company No. 267706.





DON'T WORRY, BE HAPPY

MEET THE SCIENTISTS WHOSE
RESEARCH MIGHT JUST SAVE
THE WORLD

WORDS: HAYLEY BENNETT, DUNCAN GEERE,
HELEN PILCHER AND ANDY RIDGWAY



THE NEW HERBALIST

*Superbugs are becoming more resistant to **antibiotics** by the day. Cassandra Quave is searching for a solution in forgotten herbal remedies*

Roaming around southern Italy, picking up interesting plants and having a chat with the locals might sound like a holiday, but ethnobotanist Dr Cassandra Quave assures us it's not. "You know, it's not a vacation," she says. "It's really hard work."

It's also vital work – Quave and her team from Emory University in Atlanta, Georgia, are scouring the Mediterranean for medicines that could help tackle the mounting crisis of antibiotic resistance. In the US and Europe alone, 50,000 people die each year from infections caused by resistant bacteria they picked up during a hospital stay. Without new treatments, global deaths will soon soar into the millions. Quave believes that those treatments can be found in plants.

A self-described history of medicine geek, Quave talks to local people about plants that have been used, often for centuries, in their traditional medicines. In this way, she hopes to track down those with the greatest potential for fighting infection. She admits other researchers looking for new antibiotics are dismissive about her approach because they think plants have already been found lacking. "But no one has looked at the scope of plants that we're looking at, and some of these are [already] being used in traditional medicines for fighting infection," says Quave. "Also, no one has looked at the other potential ways that these might be acting beyond just killing bugs." What's curious about some of the plant extracts that Quave has tested is that they work in a different way to the antibiotics used in clinics today. As they stop short of killing their targets – working instead against microbial communication systems – the bugs shouldn't evolve resistance to these extracts, making them an exciting prospect for future antibiotics.

The approach could work against different species of bacteria, but top of Quave's hit list is methicillin-resistant

Staphylococcus aureus, more commonly known as MRSA. Quave has something of a personal vendetta against the 'staph' bug: at the age of three, she was hospitalised for months with an MRSA infection after having part of her right leg amputated. Later, she got involved with science fair projects and became completely absorbed in the idea of bacterial resistance via news stories about *E. coli*-infested burgers. "I was an odd kid!" she jokes. MRSA is notorious as the hospital 'superbug' that causes dangerous skin infections by using wounds, burns, drips and catheters to gain access to deeper layers of the skin. Quave regularly receives letters

and emails from patients' frightened relatives, who are desperate to try any new treatment for the disease. It's a constant reminder that her ultimate goal is helping people, not making the next blockbuster drug.

So has Quave found anything on her Italian field trips that could help those individuals suffering from life-threatening skin infections? "In Italy, we asked people 'what plants do you put on the skin to treat infections, rashes... all of these kinds of things'," she says. "And sweet chestnut came up." Yes, the exact same plant that gives us roasted chestnuts at Christmas. In a recent paper, Quave's team showed that sweet chestnut leaf extract can block some of the toxic effects of MRSA and, in a mouse infected with the bug, decrease the area of skin affected, all without killing the bacteria. They've now narrowed it down to five compounds that seem

to be responsible for most of the benefit.

Quave, who practises what she preaches, making medicinal teas from plants she grows in her own garden, also hopes to validate some age-old remedies. "This is giving cultural value to people who have been using these remedies for centuries. Perhaps a healer doesn't understand the intricacies of bacterial signalling, but over time and within these cultures, they've become attuned to these plant compounds and to the resolution of disease, and I think that's exciting."

“Over time and within these cultures, they’ve become attuned to these plant compounds and to the resolution of disease, and I think that’s exciting”



Q&A

CASSANDRA QUAVE

What motivates you?

The excitement of every moment of discovery. Also, the letters I get from patients and the interactions I have with my students really keep me motivated.

Have you ever had moments when you felt like giving up?

Yes. The constant failure and rejection, especially for funding, can really wear on you. Everyone sees your successes but they don't know about the 5 to 10 failures behind every success.

What's your response to people who say your project won't work?

Well, first and foremost I try to listen to them – I'm always open to ideas and feedback – but I don't let unnecessarily dismissive comments stop my work.

If you were able to rent out a billboard in Times Square, what would you write on it?

'Stop habitat destruction, and support preservation of biodiversity and cultural diversity.' That doesn't make a very sexy headline, but that would be my main message to the public.

What will your field of research look like in 2050?

I envision a new era of medicine in which we approach drug-resistant infections in a whole new way. Advances in our understanding of how synergistic therapies work will enable us to design better medicines that quickly reduce the severity of disease and achieve cures even for difficult-to-treat, antibiotic-resistant infections.



ABOVE: MRSA bacteria (pink spheres) are resistant to many common antibiotics, making an infection hard to treat

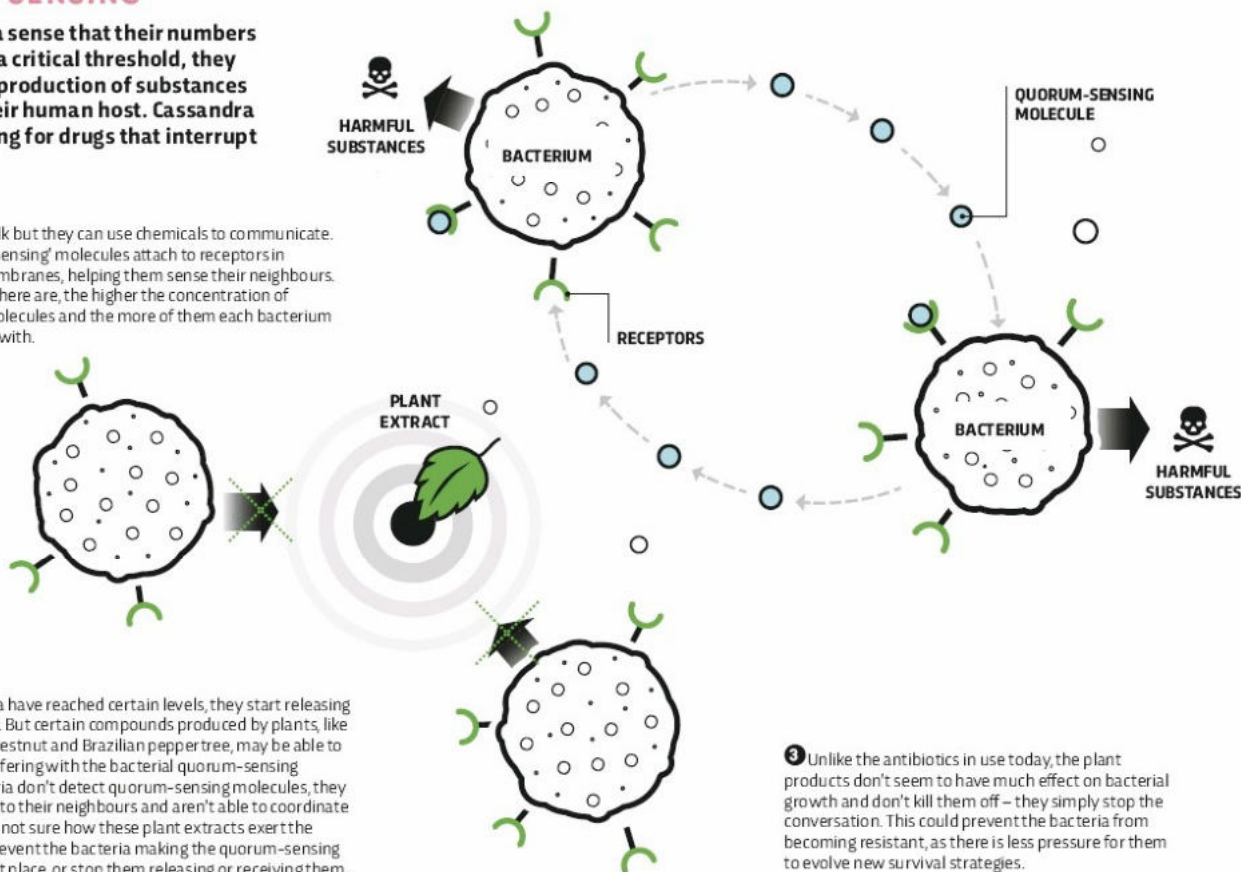
LEFT: Extracts from sweet chestnut can block the effects of MRSA

HOW IT WORKS

QUORUM SENSING

When bacteria sense that their numbers have reached a critical threshold, they switch on the production of substances that attack their human host. Cassandra Quave is looking for drugs that interrupt this process.

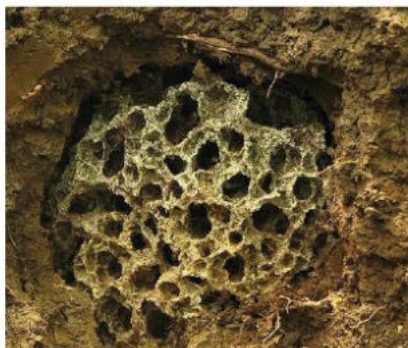
❶ Bacteria can't talk but they can use chemicals to communicate. Bacterial 'quorum-sensing' molecules attach to receptors in bacteria's outer membranes, helping them sense their neighbours. The more bacteria there are, the higher the concentration of quorum-sensing molecules and the more of them each bacterium comes into contact with.



❷ Once the bacteria have reached certain levels, they start releasing harmful substances. But certain compounds produced by plants, like extracts of sweet chestnut and Brazilian pepper tree, may be able to prevent this by interfering with the bacterial quorum-sensing system. If the bacteria don't detect quorum-sensing molecules, they are essentially 'deaf' to their neighbours and aren't able to coordinate an attack. We're still not sure how these plant extracts exert the effect – they may prevent the bacteria making the quorum-sensing molecules in the first place, or stop them releasing or receiving them.

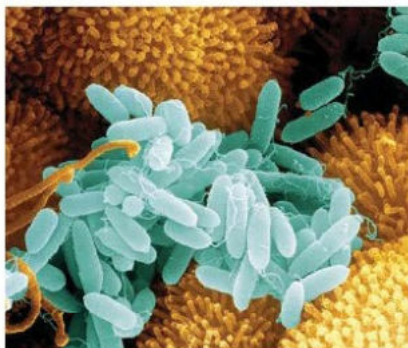
❸ Unlike the antibiotics in use today, the plant products don't seem to have much effect on bacterial growth and don't kill them off – they simply stop the conversation. This could prevent the bacteria from becoming resistant, as there is less pressure for them to evolve new survival strategies.

ALTERNATIVE MEDICINES



❶ FUNGUS-FARMING ANTS

Leafcutter ants keep fungi gardens. They cut leaves to feed to the fungi, which will in turn feed the ants' larvae. This fungi 'farming' attracts lots of unwanted microbes, but the ants combat the bugs with antimicrobials produced by *Actinomyces* bacteria that grow on their own bodies – a potential source of new drugs being studied at the University of East Anglia. Most antibiotics used today come from the same group of bacteria.



❷ CATFISH MUCUS

The striped dwarf catfish, found in Asian estuaries, may look unremarkable, but it secretes an antibiotic-filled mucus from its skin. Actually, many fish produce mucus that's rich in antimicrobials, because it helps protect them from disease. However, Indian researchers found that slime from the catfish was particularly potent against bugs that infect humans, including *Pseudomonas aeruginosa*, which causes pneumonia.



❸ THE ENDS OF THE EARTH

Scientists from the University of Illinois, Chicago, are searching in places that until recently remained unexplored for antibiotics. They plunge their test tubes into Iceland's hot springs and the muck at the bottom of freshwater lakes, to look for bacteria that produce novel compounds. They've already found bacteria in Lake Michigan that produce antibiotics capable of killing the tuberculosis bug.



THE PLANT WHISPERER

A famine crisis is looming. Stephen Long's work aims to feed the masses by supercharging the plants we eat

In the middle of the 20th Century, many parts of the world were on the brink of famine. A growing global population was butting up against the limits of food supply, with disastrous consequences. But the lives of more than a billion people were saved by a 'Green Revolution' – the spread of techniques like irrigation, hybridised seeds, and human-made fertilisers and pesticides from industrialised countries to the developing world.

Today, we're facing a similar crisis. "The UN Food and Agriculture Organization says that we're going to need 70 per cent more food by 2050, and with current rates of crop improvement we're not going to get there," says Stephen Long, director of The RIPE Project, which aims to spur a second Green Revolution by engineering crops so that they're able to photosynthesise more efficiently.

"Photosynthesis is the process that converts sunlight energy and carbon dioxide into the substance of a plant, so it's basically the source, directly or indirectly, of all of our food. We know that in crop plants this process is not actually very efficient, and we now understand enough about the process that we can start to intervene and genetically improve its efficiency."

Historically, prevailing wisdom has always been that photosynthesis couldn't be made more efficient. After all, why would evolution have not optimised such an important process? But Long points out that evolution optimises for survival and reproduction, not maximum output of the seeds and fruits that humans eat.

Meanwhile, we're living in a different environment from the time of the first Green Revolution. "A major molecule involved in photosynthesis is carbon dioxide, and in the last 50 years, through our activities, we've increased the concentration of carbon dioxide in the atmosphere by 25 per cent. That is a very short time for evolution to adapt to a change," says Long.

So, he and his team set to work proving that it was possible to boost the efficiency of photosynthesis. With funding from the Bill and Melinda Gates Foundation, they started tinkering with tobacco – a plant that's relatively easy to engineer. To begin with, his team transferred genes from *Arabidopsis thaliana*, better known as thale cress, to the tobacco plant in the hope of helping it shed heat energy more efficiently. When three variants of these engineered plants were grown, their yields were 13.5 per cent, 19 per cent and 20 per cent greater than normal tobacco plants grown as a comparison. "Although we understand photosynthesis now in plants in great detail,

it is a complex process. It's over 160 discrete steps. The first part of the project was actually simulating the whole thing on a computer. We could then try billions of manipulations, mathematically, to then see where might be the best places to intervene."

What's more, these impressive gains were achieved with minimal increases in resource costs. The engineered plants required about 1 to 2 per cent more nitrogen than the unmodified plants, and no increase in water use. "That is really the beauty of improving photosynthetic efficiency," says Long. "It's not only the efficiency with which they use light, but it's also the efficiency with which they use water and nitrogen. So in most cases, we are getting more productivity for the same amount of water, and minimal increases in nitrogen."

The big question is whether these gains in tobacco can be transferred

to food crops, and there's reason to believe that they can. Photosynthesis works in the same way in tobacco as it does in many food crops, and tests are planned to see if similar modifications can deliver increases in yields of staples like rice, cowpeas and cassava. The potential is enormous, but the clock's ticking. "Any innovation we have today is going to take about 20 years to be available to farmers at the scale we need," says Long. "So while 2050 might sound a long way off, in terms of improving crop productivity it's quite close."

“The UN Food and Agriculture Organization says that we’re going to need 70 per cent more food by 2050. With current rates of crop improvement we’re not going to get there”



Q&A

STEPHEN LONG

What keeps you feeling optimistic?

Last year the first of these manipulations gave us a 20 per cent boost in productivity. Breeders are usually happy if they can get 1 per cent. So that really showed that we were onto something. This year, two of my colleagues working on different ways of improving photosynthesis had major successes in their field trials.

Have you ever had moments when you felt like giving up?

I've certainly had moments where I've felt like giving up. For a long time, there was a very strong belief that the process of photosynthesis couldn't be improved in crops because evolution couldn't possibly have left a free lunch on the table.

What's your response to people who say your project won't work?

My response is that we now have very strong evidence from replicated field trials that it is working.

If you were able to rent out a billboard in Times Square, what would you write on it?

'Don't be complacent about our global food supply – it's at serious risk.'

What will your field of research look like in 2050?

I think the genetic tools that have been developed over the last 20 to 30 years will be being deployed at scale. So, we'll have smart crops able to deal with different environments, and be far more sustainable. That's what the technology is going to allow us. Whether we accept that technology is going to be another issue.

ABOVE:
Engineered
seedlings are
transplanted
into a field
as part of The
RIPE Project

LEFT: A stoma
on a tobacco
leaf. These tiny
pores regulate
the exchange of
gases between
the atmosphere
and a leaf's
interior. When
it's dark or
during times of
drought, they
close up so the
plants don't
lose water

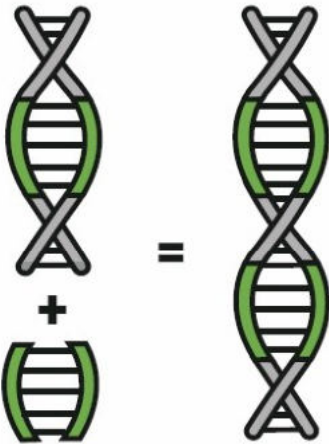


HOW IT WORKS

TURBOCHARGING PHOTOSYNTHESIS

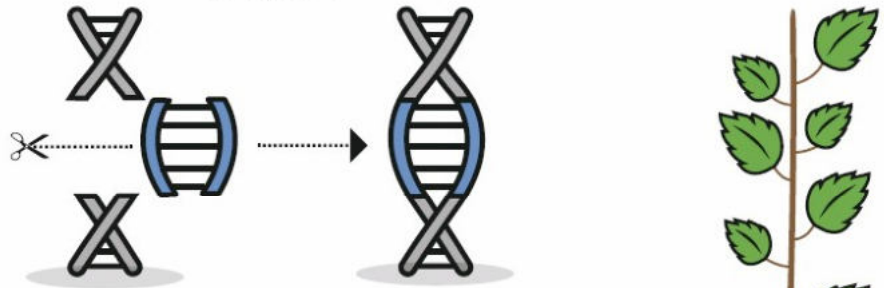
All plant cells have DNA, which contains genetic material. There are three ways that genes are being used to increase yields of crops.

METHOD 2



1 If a plant already has a particular desirable gene, then extra copies of the gene can be added to the plant's DNA to improve it even further.

METHOD 1

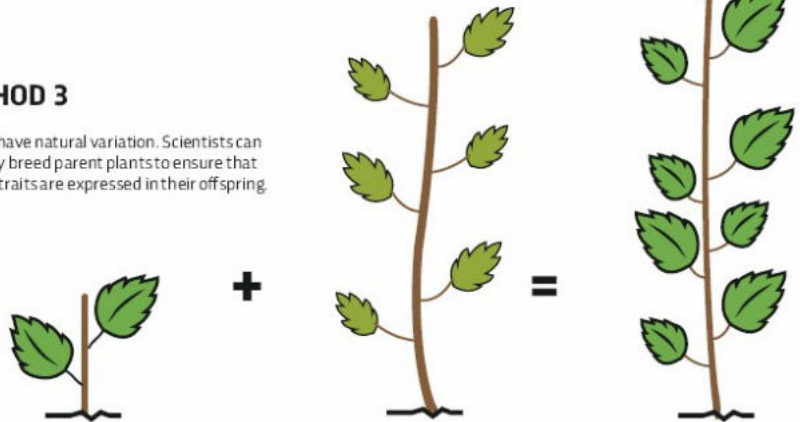


1 A specific gene that can improve metabolic pathways is snipped out from another organism (blue).

2 The gene is inserted into the plant's DNA, so the plant will become more efficient.

METHOD 3

1 Crops have natural variation. Scientists can selectively breed parent plants to ensure that desirable traits are expressed in their offspring.

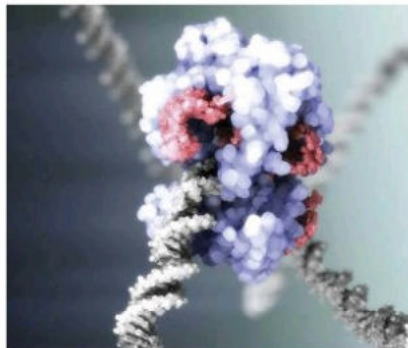


FAMINE FIGHTERS



1 ZYGO BEETLE

In South Africa, farmers have learned to fear the plant *Parthenium hysterophorus*. It uses natural herbicides to prevent other plants growing near it, causing havoc when it lands in farmers' fields. But since 2003, the country has been employing the weed's natural enemy – the Zygo beetle – to reduce its spread. Researchers at Wits University hope the beetle can establish itself throughout problematic regions and curb the weed's growth.



2 CRISPR/Cas9

Since the discovery of CRISPR/Cas9, a powerful tool for genetic editing, researchers have started figuring out ways to use it to boost crop yields. Geneticists at the Chinese Academy of Sciences, for example, have discovered how to restructure wheat genes to make the crops immune to powdery mildew, while researchers at King Abdullah University of Science and Technology gave tomatoes immunity against the yellow leaf curl virus.



3 SATELLITE DATA

It's far easier to fight a famine when you know that it's coming, so a team from the US Geological Survey has designed a system that uses satellite data to detect the unusual spikes in land temperature that often cause crop failure. During its testing phase in Ethiopia, the project was able to provide several weeks more lead time to act before families had begun to go hungry and animals had started to die.



THE CORAL MATCHMAKER

*We're in the midst of a **mass extinction** event. **Jamie Craggs** hopes his research could save coral reefs from this fate*

It's not a good time to be a wild animal or plant. Extinction rates are soaring. Every day, up to 100 species are lost forever, and it's estimated that around 25,000 species are teetering on the edge of oblivion. We live in a time of mass extinction, and nowhere is safe. In the oceans, it's thought that 60 per cent of the world's coral reefs could die over the next 20 years.

It's not all bad news, however. Species can, and have, been rescued from the brink of extinction, and sometimes their saviours can be found in the most unexpected of places, like the bowels of a south London museum. Jamie Craggs, the aquarium curator at the Horniman Museum and Gardens, is brimming with excitement because, very soon, the mini coral reefs he has so lovingly created will explode with potential new life. It's the result of five years' hard graft, working out the exact conditions needed to make captive coral spawn.

In the wild, corals like the ones Craggs is working on reproduce once a year, all on the same night and at the same time. The process, called synchronous spawning, sees coral colonies release clouds of sperm and eggs into the water, where they are mingled and dispersed by the waves and currents. It's an evolutionary adaptation that enables the sex cells of distant coral colonies to meet and mix, minimising the risk of inbreeding.

Inside coral cells are algae-like organisms called symbiotic zooxanthellae, which give them energy and colour. But rising sea temperatures are causing the zooxanthellae to desert the corals, leaving them bleached and susceptible to disease. The survivors find themselves so isolated that successful sexual reproduction is becoming difficult.

As part of his PhD at the University of Derby, Craggs has devised a closed tank system that mimics the natural environment of corals. By controlling the type and duration

of light, along with nutrient levels, water chemistry and temperature, he can reliably and predictably induce coral spawning to within half an hour. "It's a game changer," he says. "No one else has ever been able to do that before."

When the spectacle begins, thousands of tiny pink spheres, each no larger than a sugar granule, are released by the coral and float to the surface of their darkened tanks. These particular corals are hermaphrodites, so each package contains both eggs and sperm. In a UK first, Craggs and his colleagues have used them for in vitro fertilisation (IVF), yielding new coral young. "The potential is huge,"

Craggs says. "We can now make the coral in our collection spawn four or five times a year." The only limiting factors are the number of tanks and the amount of time that Craggs and his team have.

As the young corals grow and form new colonies, they provide an ever-expanding resource for scientific study. In the wild, some corals are naturally more resistant to rising temperatures, disease and pollution. With his new system, Craggs has the perfect setup to identify the features that endow these stoical individuals with their resilient nature. He can model how different corals are likely to respond to future environmental change, and critically, he hopes to breed specific individuals together to boost levels of genetic diversity, producing robust corals that are more likely to survive.

For ethical and practical reasons, Craggs's corals will never be

exported, so last year, the museum teamed up with The Florida Aquarium's Centre for Conservation. Using technology from the Horniman Museum's Project Coral, the aquarium plans to breed hardy native coral that will be used to directly restock the depleted Florida Reef Tract. After that, who knows? There's no reason why the same techniques can't be rolled out to other ailing reefs, giving the world's coral and the myriad creatures that depend on it the chance of a brighter, more colourful future.

"Sure enough, at 1pm, the spectacle begins. In darkened tanks, thousands of tiny pink spheres, each no larger than a sugar granule, are released by the coral and float to the surface"



Q&A

JAMIE CRAGGS

What keeps you feeling optimistic?

I think there are pockets of hope. There are some highly resilient corals out there that seem to do well despite challenging environmental conditions, and there are also still some pristine reefs left.

Have you ever had moments when you felt like giving up?

One time, early on, I missed the coral spawning because I thought it wasn't going to happen and I went home. It was absolutely heartbreaking, but it made me realise that we needed to control the spawning, and led to the setup we have today.

What's your response to people who say that your project won't work?

I think they just need to come down and spend some time with us and see what we've achieved. What we're developing here is going to underpin and support lots of other great, positive work.

If you could have a billboard in Piccadilly Circus, what would you write on it?

A picture tells a thousand words, so I'd put up photos of coral reefs: the colourful, healthy, vibrant ones full of fish and then the bleached, damaged, empty, dying ones... before and after shots.

What will your field of research look like in 2050?

In much the same way that people grow trees in nurseries today, I think we'll find coral being grown in land-based nurseries on a large scale, and then used to restock the reefs.



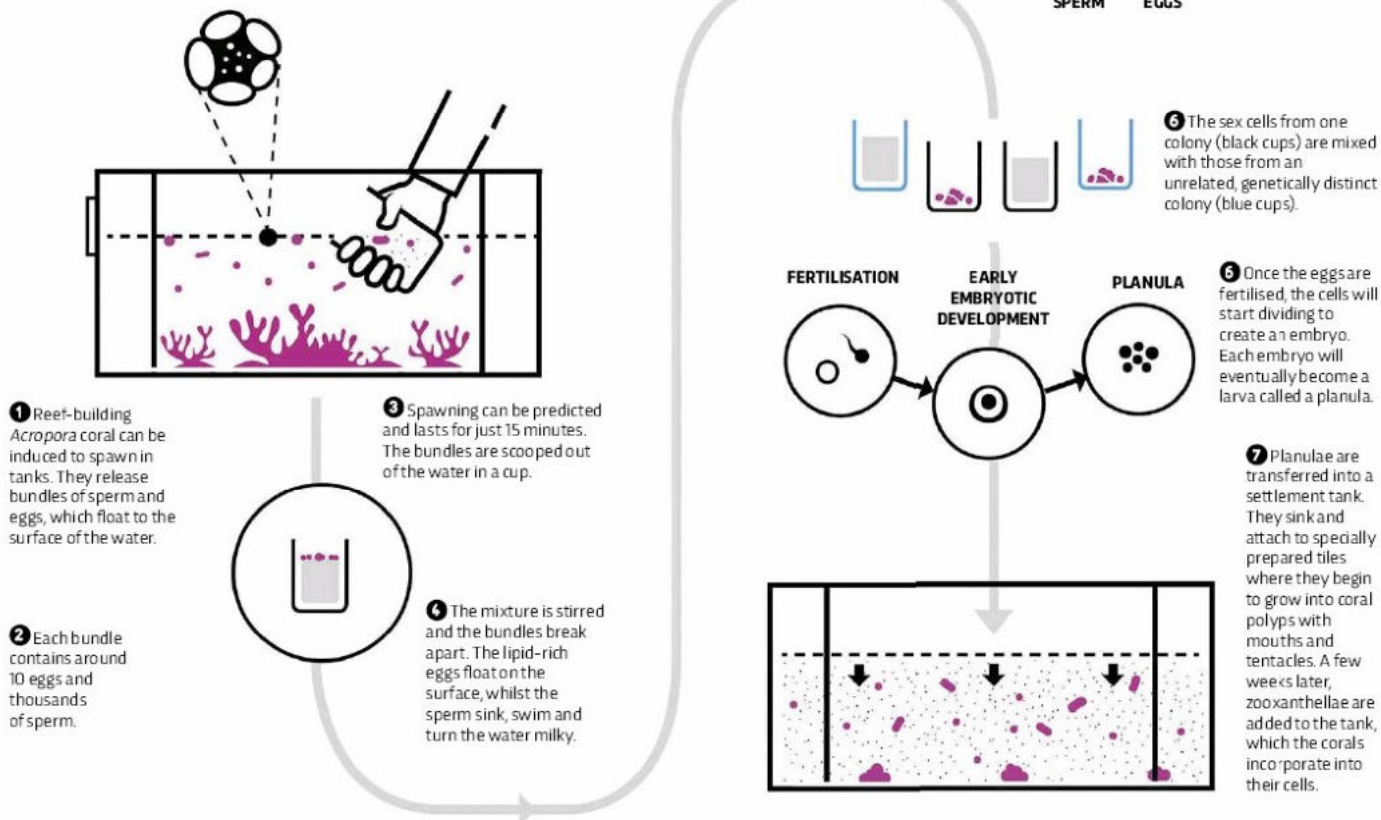
ABOVE: Resembling a starry night sky, spawn from a colony of coral is released in the Cayman Islands

LEFT: These corals in North Sulawesi have bleached in response to a rise in sea temperature

HOW IT WORKS

CORAL IVF

With the right conditions, some coral species can be induced to spawn in the lab.



SAVE OUR SPECIES



1 THE FROZEN ZOO

At San Diego Zoo Institute for Conservation Research, scientists have created a 'frozen zoo' of cells and embryos from endangered and extinct species. As the largest, most diverse collection of its kind, the initiative seeks to preserve the world's biodiversity in cellular form, and provide material for research and conservation projects. Attempts to rescue the northern white rhino, of which there are just three left, focus on sperm samples stored at the zoo.



2 GENETIC MODIFICATION

The endangered black-footed ferret could become the first wild animal to have its DNA deliberately altered. The species suffers from inbreeding and sylvatic plague, which threaten its existence. Scientists from Revive & Restore, a US non-profit organisation pioneering the use of genetics in conservation, want to edit its genome to make it disease-resistant, and clone ferrets from the cells of dead individuals to restore genetic diversity.



3 GENOME LIBRARIES

The kākāpō is a flightless parrot endemic to New Zealand. Decimated by invasive species, the 151 birds alive today are the focus of a conservation programme. They live on predator-free islands, where they are monitored and breeding is managed. Some birds are artificially inseminated, and chicks are sometimes fostered by experienced kākāpō mothers. The genome of every living kākāpō is being decoded in an effort to guide future conservation.



THE CLOUD CHASER

*If we learn how to influence the weather, **climate change** could be slowed.*

Anna Possner is crunching the numbers to find out what the consequences might be

We see them almost every day, but there's a lot we don't know about clouds. Even to meteorologists, their inner workings are somewhat hazy. And that matters, because clouds play an important role in regulating the planet's temperature – both reflecting radiation from the Sun and acting like a blanket, keeping the Earth's heat in. In fact, some clouds are so effective at the reflecting bit that 'supercharging' them by making them even brighter and whiter has been suggested as a way to reduce temperatures and fight global warming.

It's an idea that atmospheric scientist Anna Possner is very familiar with. Her research at the Carnegie Institution for Science in Stanford, California, will help to answer the question of whether 'cloud brightening' might actually work. She's part of the Marine Cloud Brightening Project, an initiative that's brought together cloud experts in the US and UK with a bunch of retired Silicon Valley engineers to find out whether spraying tiny droplets of seawater into clouds can brighten them enough to cool the planet – and do so without any nasty side effects.

Possner runs experiments with clouds, looking to see what happens when she injects droplets of seawater into them. But the clouds Possner works with are made up of numbers – they are numerical representations of the real thing created using algorithms that model how atmospheric systems work. So complex are these models that they require supercomputers – such as those at the National Center for Atmospheric Research's (NCAR) centre in Wyoming – to run. "You run your models and you get output files that are usually four-dimensional – time and 3D space of various fields such as temperature, pressure, cloud water and cloud reflectivity," says Possner.

Now a postdoctoral research scientist at Carnegie, it was Possner's research for her PhD at ETH Zurich, Switzerland, that led to her connection with cloud brightening. Here she studied ship tracks, which are the shipping equivalent of

aircraft contrails. These slender strips of brightened cloud form as ships crossing oceans belch out tiny aerosols, such as sulphate particles, from their smoke stacks. It's around these tiny particles that water vapour in the atmosphere condenses, making the clouds more reflective. It's exactly the same principle behind cloud brightening, except the particles that would supercharge the clouds would be saltwater.

Cloud brightening, like most geoengineering projects, is controversial. The biggest concern being that meddling with our weather systems might have unforeseen knock-on effects, and could actually make things worse. This controversy makes funding for such research hard to come by. It also makes young atmospheric scientists like 30-year-old Possner

tentative about getting involved. "I'm not saying I'm in support or against it really, we have just got to start this now in terms of research. This is an idea that's out there, and if people expect the scientific community to make a qualified statement about the possibilities and limitations of this method, it requires coordinated research."

Possner's virtual clouds are helping to plan the next stage of the project – where seawater will be sprayed into real clouds, rather than numerical ones, to measure what happens. At first, the plan is to run experiments on land at Moss Landing on the

Californian coast before starting trials out at sea. Exactly when these experiments will happen is dependent on funding. "If you want to see whether this will work, you've got to test it in the field," says Possner. "That's where marine cloud brightening has a benefit – you can test it in the small scale without it having a long-term impact. Sea salt sediments out of the atmosphere quickly, and you're not spraying anything that isn't there already."

For Possner, the big draw of cloud brightening research is understanding the basic physical process of how microscopic particles, such as sea salt and dust, interact with the atmosphere to generate and grow clouds. These aerosol-cloud interactions, as they are known, are one of the biggest unknowns in climate science, and figuring them out will give scientists a much better idea of what's in store for our fragile planet.

“Could spraying tiny droplets of seawater into clouds brighten them enough to cool the planet – without nasty side effects?”

Q&A

ANNA
POSSNER**What motivates you?**

The role of clouds in a changing climate is something we've not fully understood for decades. Now we are at a stage where we have computational capabilities and planned experimental initiatives, like the cloud brightening project, with which we can hope to really make headway.

Have you ever had moments when you felt like giving up?

Doing research sometimes feels like living on a rollercoaster. Sometimes you do not make headway for months, which can be immensely frustrating. However, it's then even more rewarding when you have a breakthrough.

What's your response to people who say that your project won't work?

We don't know whether marine cloud brightening will work, but this project offers us an opportunity to run experiments and collect valuable data, not just for the cloud brightening project but for understanding aerosol-cloud interactions in general.

Where do you see the planet in 30 years?

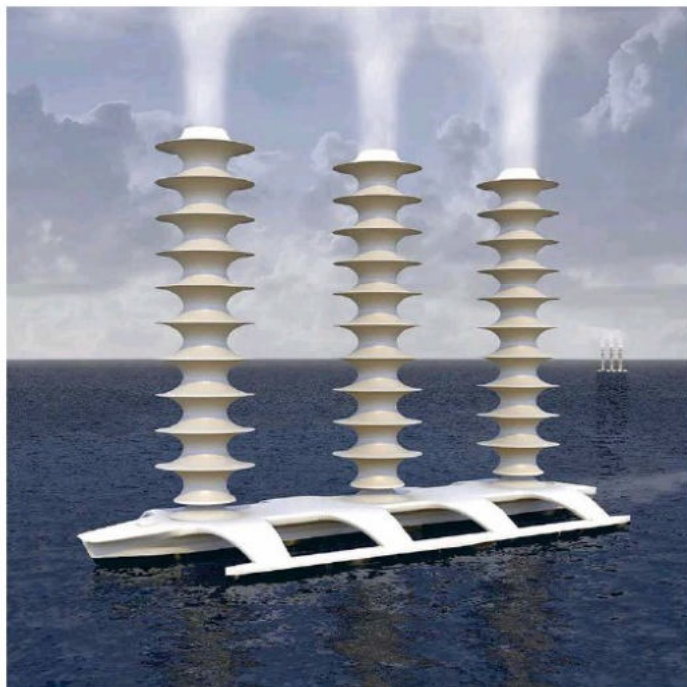
I'd like to see a really consolidated effort to move from fossil fuels to low carbon alternatives that are economically competitive, and I'd also like to see more hybrid cars on the road, if not electric.

What will your field of research look like in 2050?

It's a really exciting time in climate modelling. We've started moving away from modelling individual regions over short time periods. In the future, we'll be able to model the entire Earth at kilometre, or even sub-kilometre, resolution [the distance between the data points within the model] over long periods, which will hugely improve the accuracy of our climate predictions.

ABOVE: The tracks in these clouds are caused by tiny particles that have been released from ships. Water vapour condenses around the particles, making the clouds brighter

LEFT: Concept of a yacht that would spray seawater into clouds to make them brighter



HOW IT WORKS

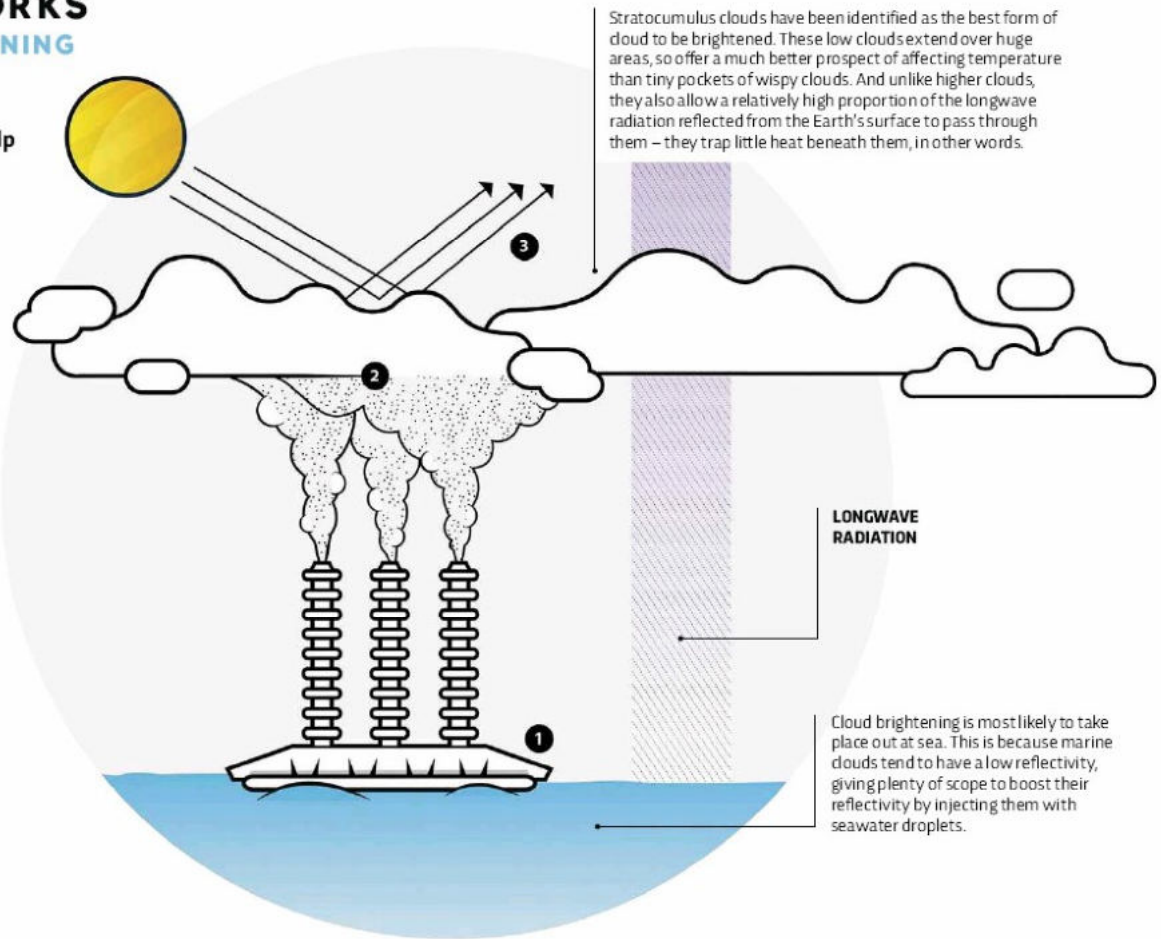
CLOUD BRIGHTENING

Clouds sprayed with seawater reflect more sunlight, which could help reduce the planet's temperature.

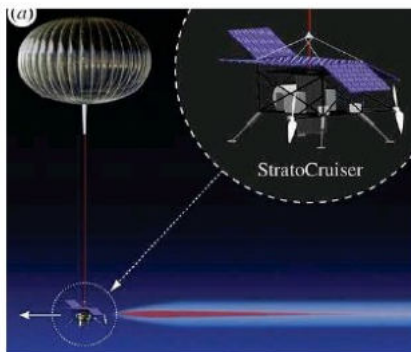
③ A higher proportion of shortwave radiation from the Sun is reflected by the clouds that have been brightened. This reduces temperatures at the sea surface.

② When the seawater particles reach the clouds, water vapour condenses around them. The water droplets they form in the clouds are small, resulting in more scattering of incoming light because there are more surfaces for the light to reflect off.

① Nozzles on board a ship pump tiny particles of seawater into the air. The nozzle already developed by Marine Cloud Brightening Project engineers is capable of generating three trillion particles a second.



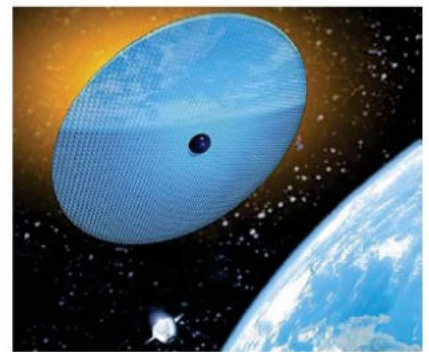
CLIMATE CONDITIONERS



① **SUPERCHARGE THE STRATOSPHERE**
Instead of making clouds brighter, another idea is to release particles into the atmosphere that can reflect the Sun's radiation themselves. This year, Harvard professors David Keith and Frank Keutsch, designers of the Stratospheric Controlled Perturbation Experiment (SCoPEX), plan to launch a high-altitude balloon 20km into the air near Tucson, Arizona, and spray a small quantity of calcium carbonate particles to see what happens.



② **OCEAN SEEDING**
"Give me half a tanker of iron, and I will give you an ice age," said the late oceanographer John Martin in 1988. Although he was half joking, Martin stood by his idea of using iron to boost plankton and increase the carbon dioxide taken up from the atmosphere. Since then, several tests have been carried out. A key question is how much of the plankton will actually sink to the seabed, locking the carbon away from the atmosphere.



③ **SPACE REFLECTORS**
It sounds implausible – place a giant reflective sunshade in space to block off some of the sunlight that reaches Earth. Wacky as it sounds, this idea has been receiving some consideration: in a report by the Royal Society, it was suggested that in the long-term, some form of space sunshade may be cheaper and less risky than a geoengineering project in the stratosphere. Tests are currently confined to modelling effects of various approaches.

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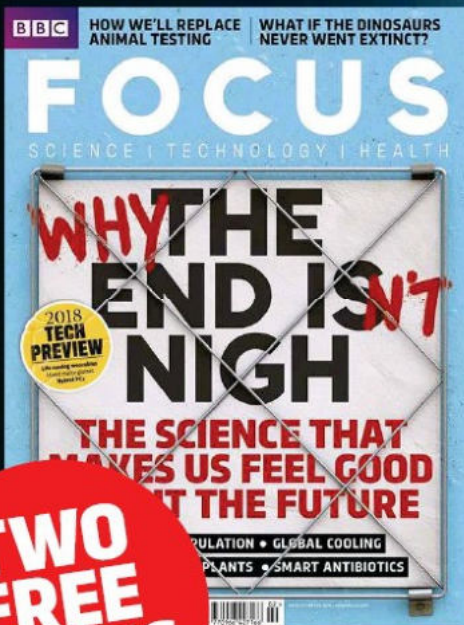
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Kirk Rutter's
severe depression
improved after he
took psilocybin

PSYCHEDELIC HEALING

At any given moment, more than 3 per cent of the UK population are thought to be suffering from depression.

For some people, like Kirk Rutter, symptoms persist despite treatment. Could psilocybin – the psychedelic drug found in magic mushrooms – help to put an end to depression by ‘rebooting’ the brain?

WORDS: KAT ARNEY

PHOTOGRAPHY: FRAN MOIRIS

WARNING

Psilocybin and hallucinogenic mushrooms are a Class A drug according to UK law. Anyone caught in possession of such substances will face up to seven years in prison, an unlimited fine, or both. More information and support for those affected by substance abuse problems can be found at bit.ly/drug_support

Kirk never got over the death of his mother. When she passed away in 2011 after a long illness, the 47-year-old IT specialist kept himself busy by organising her funeral and dealing with the other administrative tasks that come with a death in the family. But while his father and brother managed to pick themselves up and move on, he struggled to come to terms with the loss.

"After the funeral was over there was nothing left to organise or create, and I found myself in a kind of void that just persisted until I was overwhelmed," he says. "After six months I was still talking about her death, and I wondered whether I should be over it by now. Should I have moved on? Should I be better? But I didn't really feel that way – I kept feeling worse and worse until I was just chronically sad all the time."

Eventually, Kirk spiralled into a deep depression that reached into all areas of his life. He signed up for counselling and visited a therapist every week for a year. It didn't work. His GP prescribed a number of different antidepressants, but they didn't work either. "The drugs just turned me into a zombie," he says. "And although I talked through everything else in my life during counselling, I just couldn't talk about the grief. It was too difficult. When I felt it bubbling up I would just change the subject."

Every year, thousands of people in the UK are diagnosed with depression and these numbers keep rising. While antidepressants are a common treatment, studies suggest that more than half of all patients don't respond to the first drug they're given. A significant proportion of people with depression fail to find something that works for them, ending up cycling through periods of treatment and relapse.

In search of a more effective approach, researchers at Imperial College London have been finding out whether the mind- and mood-altering properties of psychedelic drugs such as psilocybin (the active ingredient in magic mushrooms) could be helpful for treating psychiatric conditions. Led by Dr Robin Carhart-Harris, a team of researchers have been running a clinical trial testing the effects of psilocybin on a small group of people with intractable depression. People just like Kirk.

THE PSYCHEDELIC SPA

"We'd been doing brain imaging studies looking at the effects of psilocybin which suggested that it might have antidepressant effects," explains Carhart-Harris. "We also knew that psychedelic drugs can dissolve the ego [the sense of 'self'] temporarily. This is accompanied by the possibility of emotional, personal, philosophical and existential insight, so it was a case of joining the dots."

PHOTOS: THOMAS ANGUS/IMPERIAL, SCIENCE PHOTO LIBRARY, MENDEL KAELEN

"I was open to something potentially a bit more healing than just trying to gloss over the feelings or chemically dull them"



ABOVE: The volunteers took psilocybin in a safe, relaxing environment, to reduce the risk of experiencing anxiety or a bad trip



ABOVE: These MRI scans show a 'normal' brain (left) and a brain under the influence of LSD (right). It is thought that psilocybin may affect the brain in a similar way to LSD – both hallucinogens have been trialled to treat depression



ABOVE: Dr Robin Carhart-Harris, who is carrying out the psilocybin research

BELOW: Various magic mushrooms are found throughout the world



Spurred on by a previous study showing that people who took psilocybin reported a long-term increase in psychological wellbeing and a trial showing the drug's benefits for treating anxiety and depression in terminal cancer patients, Carhart-Harris put together a plan to test whether it could relieve treatment-resistant depression.

Despite receiving some funding from the Medical Research Council in 2012, the proposal was hampered by ethical and regulatory red tape, as well as the challenge of obtaining clinical-grade psilocybin. But after three frustrating years Carhart-Harris was finally able to start recruiting patients for his unconventional clinical trial, and Kirk was one of them.

"I was open to something potentially a bit more healing than just trying to gloss over the feelings or chemically dull them," Kirk says. After an initial interview over the phone, he was invited to come to Imperial College's clinical research facility in London for a longer discussion and a lengthy questionnaire. Next was an orientation session, allowing Kirk to get used to the environment in which the drug would be administered.

He was taught a grounding technique to combat anxiety and stay anchored in reality. Then came a blindfold and headphones playing a specially curated music selection ranging from ambient sounds and tribal rhythms to soaring opera, interspersed with short periods of silence. (Listen to the playlist at mendelkaelen.com/music.html)

"I went into this hospital room and it was done up like a psychedelic spa!" he laughs. "There were throws, imitation candles, aromatherapy machines – it was very relaxing. So, when it came to actually taking the first dose of psilocybin I felt reassured because I'd seen the room and heard the music, I'd been in that space and thought it was a nice environment."

TRIPPING ON TRIAL

The researchers tested 19 volunteers with two doses of psilocybin – 10mg and 25mg – given a week apart, each with an MRI scan before and afterwards. While the first dose is relatively low so the participants get used to the sensation, the second one packs a bigger psychedelic punch.

"It's a big trip, and it's probably more than people would take recreationally," explains Carhart-Harris. "That's the kind of dose required to produce ego dissolution, ●

THE SCIENCE OF PSYCHEDELICS

At a molecular level, psilocybin works on the serotonin system in the brain. Serotonin is a neurotransmitter that sends signals between neighbouring nerve cells. It's often described as the 'happy chemical', but in fact there is a complex and poorly understood relationship between serotonin and mood.

Psilocybin sticks to the serotonin 2A receptor – 1 of 14 different types of serotonin receptor found on nerve cells – and appears to induce a state known as plasticity, where systems and pathways in the brain can be reset. A principal system affected by psilocybin is the default mode network, which is involved in higher-level conscious functions including our sense of self

(ego) and the story we construct about our identity and place in the world.

Depression is characterised by entrenched, intrusive thought patterns, reflected by abnormal activity in the default mode network. Under the influence of psilocybin, this network seems to temporarily dissolve and break down, leading to a loss of self-identity and a strong sense of interconnectedness with the rest of the world. It literally opens the mind.

By breaking down these embedded systems and allowing them to reform in a new way, psilocybin can help to 'reset' the brain. This could provide a way for people to break free from their depression and move towards healthier thought patterns.

• the sense of oneness that has been said to be at the core of what some people describe as a mystical experience on psychedelics. It's a massive trip, but they're doing it in a controlled way in a clinical research facility with psychiatrists, beautiful music, low lighting, nice furnishings, and an emergency medical response team on hand in case anything goes wrong."

For Kirk, this higher dose produced a profound effect. "After taking the higher dose I started seeing this weird Sanskrit writing, then it got a lot busier and more psychedelic," he says. "The music played a big part of the experience – it's like a river guiding you through a landscape. I remember an operatic piece that felt like I was being lifted up and it was all washing over me, then it guided me to a sad place where all the grief came up. At one point my eyeshade was so wet I had to wring it out because I'd let go of so much sadness."

This intense emotional release enabled Kirk to finally address the feelings he had buried since the death of his mother.

"Right afterwards I felt very relaxed and spaced out, and I had a really good sleep that night," he says. "There was a lot of processing that happened, coming to terms with the grief. There will always

"At one point my eyeshade was so wet I had to wring it out because I'd let go of so much sadness"

be that sense of loss, but I'm not crushed by it like I was before and I've become much less withdrawn at work and socially. A week after the treatment I was out shopping with a friend and I just had this sensation of space around me. I realised it was a feeling of optimism that I hadn't had for so long, and it felt really good."

Overall, the results of the trial were impressive. Psilocybin caused no significant side effects other than mild nausea and headaches in some people, and didn't lead to any unpleasant flashbacks. More importantly, it seemed to work. All the participants had a reduction in their depression symptoms, with those who had the most extreme psychedelic experiences having the greatest improvement – an effect that has persisted in the long term. Two years after taking part in the study, Kirk is still feeling well and hasn't returned to taking antidepressants.

Carhart-Harris also saw a difference in the brain scans of volunteers after they'd undergone the treat-



ment. He noticed that certain networks in the brain seemed to break down under the influence of psilocybin and reformed again afterwards, particularly the default mode network – a system in the brain that is associated with our internal world and sense of self (see box, left). He also saw a boost in responsiveness in a region of the brain called the amygdala, which is associated with emotions – the opposite of the emotional flattening that many people experience when taking conventional antidepressants.

“The default mode network is over-engaged in people with depression and it’s hard to turn it off, so they get stuck in a rut in their own head. When people are in the throes of an intense psychedelic experience the default mode network will be quite markedly disintegrated,” he says, pointing out that the people who showed the most clear reformation of the default mode network after taking the drug were those who improved most after treatment.

“With psilocybin, you take a system that is somehow functioning abnormally and shake it up in a controlled setting – you scramble it up, melt it, shake it up – and then you let it reformat, and maybe it resets in a way that is somehow healthier. There is a loss of sense of self and identity, but what replaces it is a sense of being connected to nature and other people and the Universe,” says Carhart-Harris.

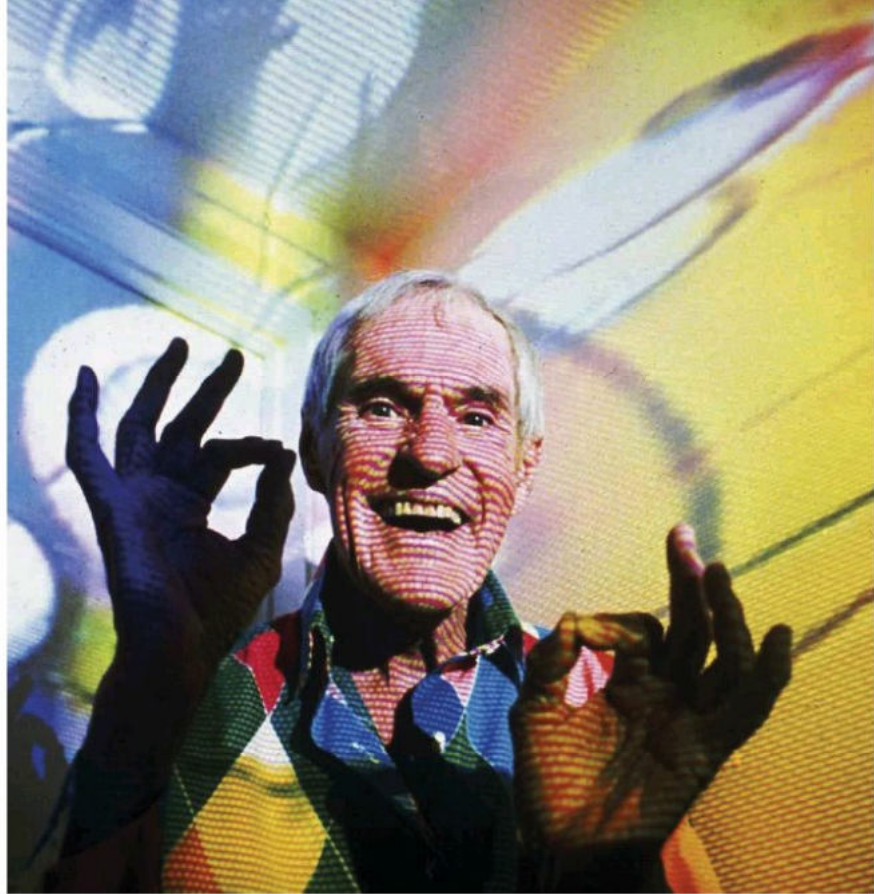
DON'T TRY THIS AT HOME

Although the results from the trial are promising, Carhart-Harris cautions against trying psychedelics without medical supervision. For a start, psilocybin and magic mushrooms are Class A drugs in the UK and carry heavy penalties for possession or supply. There are also significant psychological risks.

“Psychedelics induce a state of sensitivity and vulnerability,” he explains. “People are in a state of special psychological plasticity just like children are, and they’re sensitive to context and emotion more than they ordinarily would be. It’s important that they are nurtured and protected – if the conditions aren’t right then the experience can be bad and you can potentially harm people.”

Carhart-Harris is planning a new trial which is due to start recruiting up to 50 patients in early 2018, comparing a single dose of psilocybin with a six-week course of the ‘gold standard’ antidepressant drug escitalopram. He also thinks that psilocybin therapy could be beneficial for many other psychological conditions involving embedded or repetitive thought processes, including anxiety, eating disorders, obsessive compulsive disorder, chronic pain and post-traumatic stress disorder (PTSD). And he’s keen to explore whether it could help prevent people in the early stages of depression from sliding into the kind of deep despair that Kirk experienced.

“Prescriptions of antidepressants are going up year-on-year but a lot of people don’t want to take them – often for valid reasons – so we shouldn’t prevent them from having access to psilocybin




ABOVE: In the 1960s, while a faculty member at Harvard, Dr Timothy Leary carried out psilocybin studies on volunteers. However, his studies had a lack of scientific rigour and did not follow correct research protocol. He was fired from the university and thrown out of academia, but became a figurehead for the counterculture and drug movement

treatment,” he says.

Yet despite the potential of the drug, funders and policymakers remain wary of psilocybin’s reputation, much of which stems from unchecked or unethical research practices dating back decades. For example, the US military is known to have carried out experiments aimed at weaponising hallucinogenic drugs including psilocybin, while Harvard psychologist Timothy Leary gained notoriety for his mind-expanding psychedelic explorations in the 1960s.

Due to the difficulties in gaining funding for his work, Carhart-Harris’s research is currently supported by private donations. A UK-based start-up company, Compass Pathways, is also seeking funding to carry out a larger-scale clinical trial of psilocybin across Europe. But although he’s excited about the potential for psychedelic drugs, Carhart-Harris also knows that the underlying research base needs to be solid, and a lot more work remains to be done.

“I’m not wanting to romanticise these compounds or preach about them – there are risks and things have to be done properly and carefully. This is a real opportunity for a major paradigm shift in psychiatry, but it needs to happen at the right pace. We can’t push it too hard too soon and repeat the mistakes of the past,” he says. 

Kat Arney is a science writer, presenter and broadcaster. Her latest book is *How To Code A Human* (£16.99, Andre Deutsch).

DISCOVER MORE



Watch a clip from *The Brain: A Secret History* in which BBC presenter Michael Mosley take a dose of psilocybin at bit.ly/psilocybin_brain



To listen to an episode of *In Our Time* about feathered dinosaurs, visit bbc.in/2DX3GMy

WHAT IF THE DINOSAURS HAD SURVIVED?

If the dinosaurs hadn't been wiped out in a mass extinction 66 million years ago, the world would look very different today

Words: John Pickrell Illustrations: James Gilleard

Artist's impression of how dinosaurs could have looked, if they had survived







round 66 million years ago, a 14km-wide asteroid smashed into our planet. An estimated 15 billion tonnes of soot spread through the atmosphere, creating one long night that lasted several years and made

photosynthesis all but impossible. It heralded an endless winter that saw average temperatures fall by as much as 28°C. These are the conditions that the few wretched creatures that survived the initial impact had to endure – not to mention the earthquakes, tsunamis, wildfires and volcanic eruptions that swiftly followed in its wake.

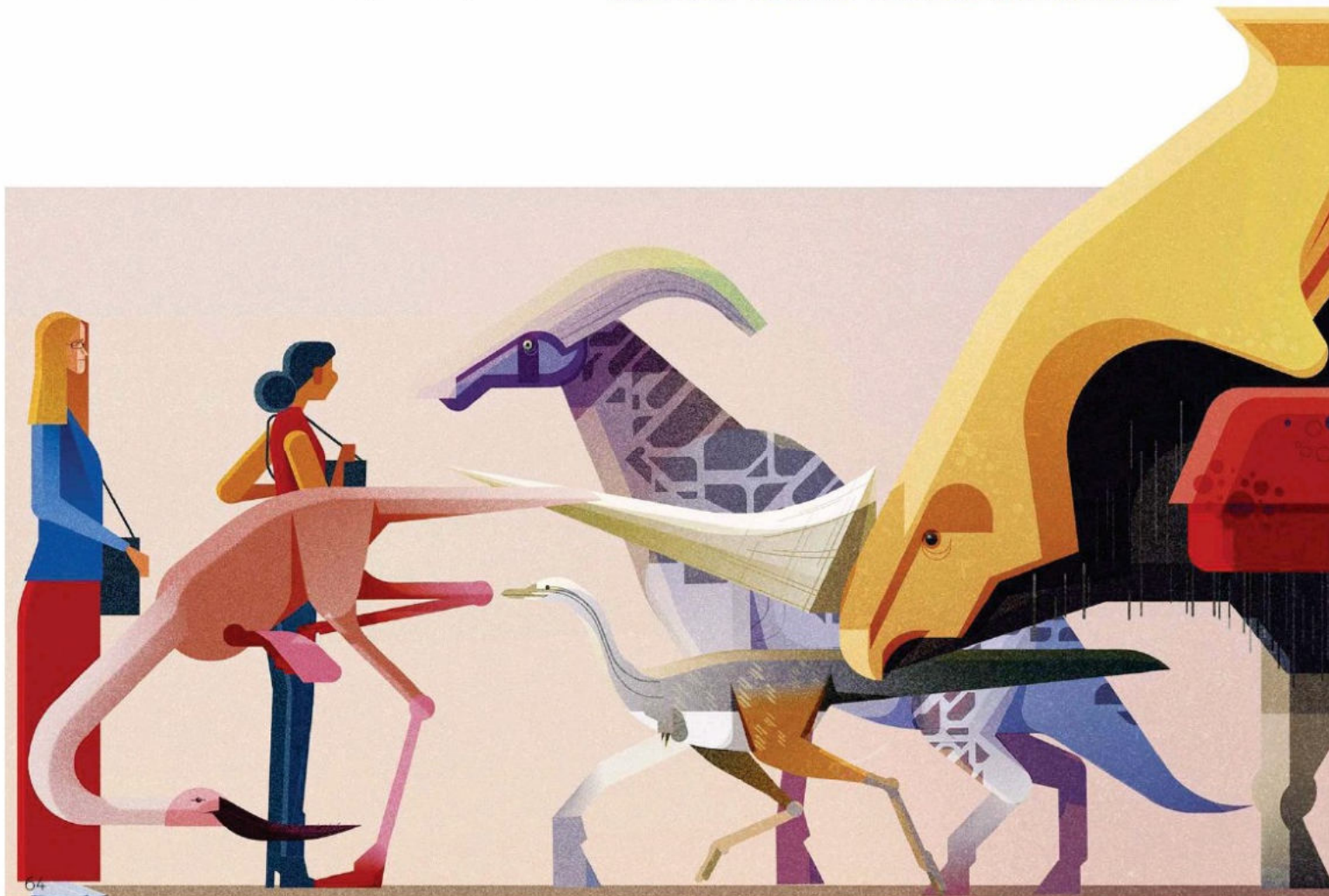
Around three-quarters of all species went extinct and no animal bigger than a Labrador dog survived. But according to researchers at the University of Texas, things could have been very different. They reported findings that had the asteroid struck Earth just a few minutes earlier, it would have hit the deep ocean rather than the shallow sea of the Yucatan Peninsula in present-day Mexico.

Had that been the case, then the damage would have been more localised. Some of the dinosaurs far from the impact site might have survived, and the world would be a different place today. In our

own history, only the feathered theropod dinosaurs (a group of bipedal dinosaurs) we know as birds made it through the calamity, but how would things have turned out if their larger relatives had joined them? Would dinosaurs still be alive today and could mammals such as humans have evolved? What would our world look like if we shared it with the descendants of animals like *T. rex* and *Triceratops*?

“I’m sure a fairly nice diversity of non-avian dinosaurs would still be here,” says Dr Stephen Brusatte, a palaeontologist at the University of Edinburgh. “If there was no sudden, catastrophic shock of the asteroid, I really don’t see anything that’s happened since – whether it was the spread of grasslands; changing ocean currents; the separation of Antarctica

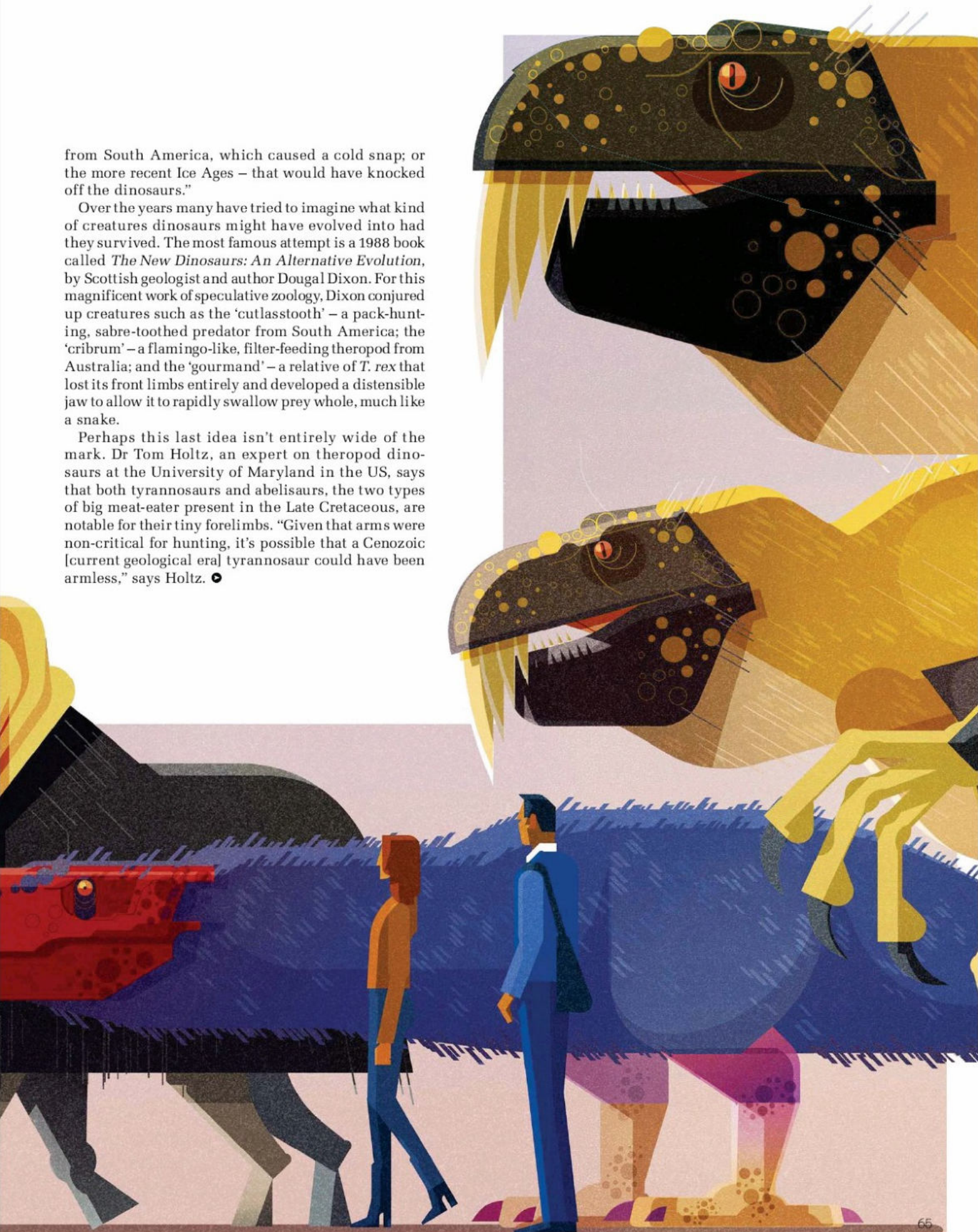
“Given that arms were non-critical for hunting, it’s possible a tyrannosaur could have been armless”



from South America, which caused a cold snap; or the more recent Ice Ages – that would have knocked off the dinosaurs.”

Over the years many have tried to imagine what kind of creatures dinosaurs might have evolved into had they survived. The most famous attempt is a 1988 book called *The New Dinosaurs: An Alternative Evolution*, by Scottish geologist and author Dougal Dixon. For this magnificent work of speculative zoology, Dixon conjured up creatures such as the ‘cutlasstooth’ – a pack-hunting, sabre-toothed predator from South America; the ‘cribrum’ – a flamingo-like, filter-feeding theropod from Australia; and the ‘gourmand’ – a relative of *T. rex* that lost its front limbs entirely and developed a distensible jaw to allow it to rapidly swallow prey whole, much like a snake.

Perhaps this last idea isn’t entirely wide of the mark. Dr Tom Holtz, an expert on theropod dinosaurs at the University of Maryland in the US, says that both tyrannosaurs and abelisaurids, the two types of big meat-eater present in the Late Cretaceous, are notable for their tiny forelimbs. “Given that arms were non-critical for hunting, it’s possible that a Cenozoic [current geological era] tyrannosaur could have been armless,” says Holtz. ●



THE DINOSAURS THAT COULD HAVE BEEN

If the dinosaurs had continued to evolve, all kinds of new body forms might have developed

① Dino-monkeys

Once flowering plants appeared in the Cretaceous, there was no stopping them. Fruit became abundant during the Cenozoic, so tree-dwelling, primate-like feathered dinosaurs may have evolved to take advantage of the sugary goodness.

② Burrow dwellers

Curiously, few known dinosaurs appear to have used burrows – perhaps given more time, rodent- or mole-like species may have evolved to exploit the subterranean environment.

③ Woolly wonders

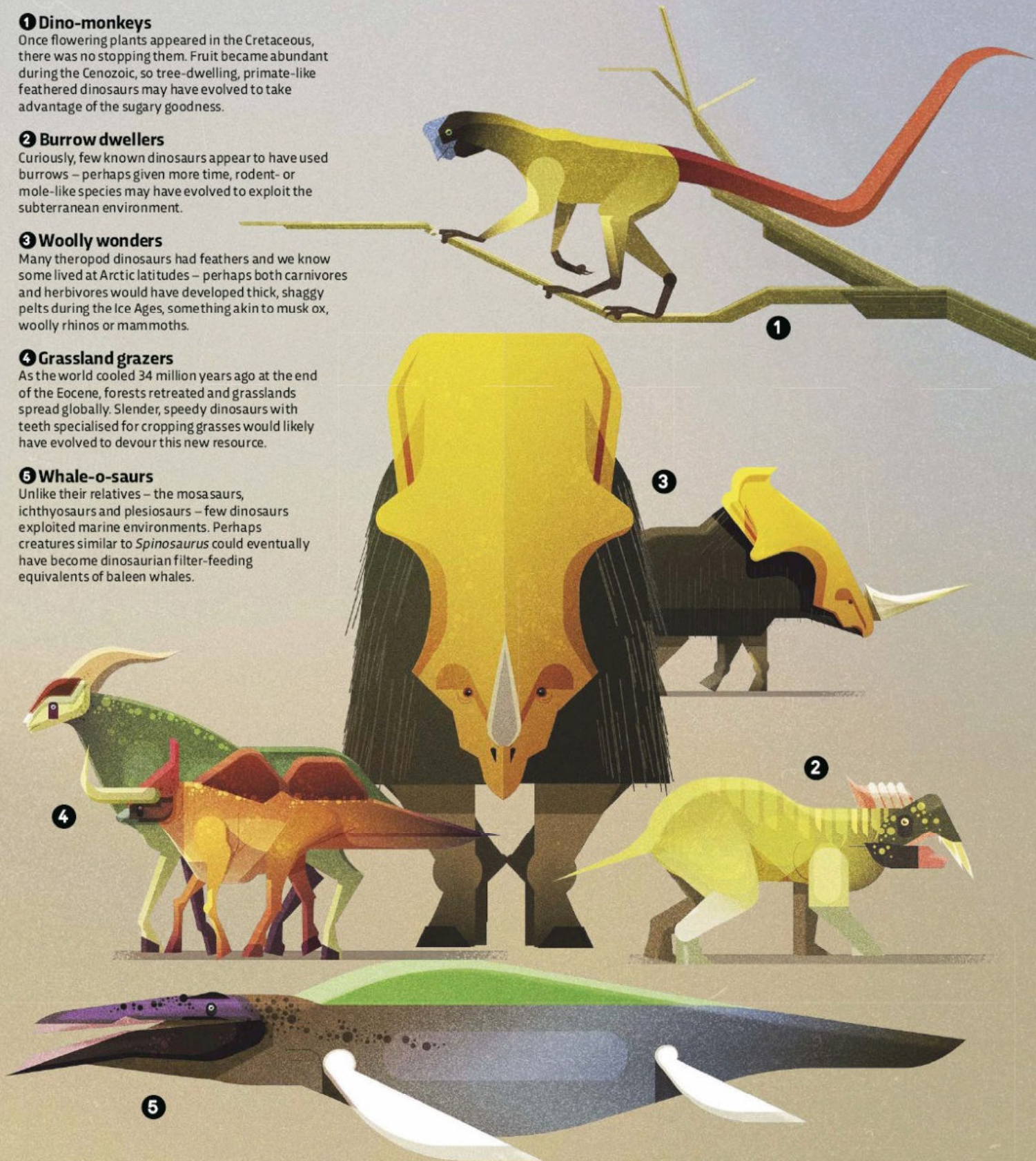
Many theropod dinosaurs had feathers and we know some lived at Arctic latitudes – perhaps both carnivores and herbivores would have developed thick, shaggy pelts during the Ice Ages, something akin to musk ox, woolly rhinos or mammoths.

④ Grassland grazers

As the world cooled 34 million years ago at the end of the Eocene, forests retreated and grasslands spread globally. Slender, speedy dinosaurs with teeth specialised for cropping grasses would likely have evolved to devour this new resource.

⑤ Whale-o-saurs

Unlike their relatives – the mosasaurs, ichthyosaurs and plesiosaurs – few dinosaurs exploited marine environments. Perhaps creatures similar to *Spinosaurus* could eventually have become dinosaurian filter-feeding equivalents of baleen whales.



“You can’t underestimate the importance of that extinction really hitting the reset button for mammals and clearing the playing field”

● The beginning of the Cenozoic Era (which spans the period from 66 million years ago until the present day) might essentially have been an ecological extension of the Late Cretaceous. Various creatures such as titanosaurs (huge, long-necked dinosaurs like *Argentinosaurus*), hadrosaurs (duck-billed dinosaurs like *Edmontosaurus*), ceratopsians (horned, beaked dinosaurs like *Triceratops*), and predators such as the tyrannosaurs would still have remained common.

But as we head further from the Cretaceous towards the present day, there would likely have been significant changes, says Dr Andy Farke at the Raymond M. Alf Museum of Paleontology in Claremont, California. “If dinosaurs were still around today they’d be pretty different to what we think of at the end of the age of the dinosaurs – things like *T. rex* and *Triceratops*,” he argues. “You might still recognise them as a dinosaur, but who knows what kind of body shapes and body plans might have come up in the past 66 million years.”

Many of the mammals with which we’re familiar might not have had the opportunity to evolve. “You can’t underestimate the importance of that extinction 66 million years ago in really hitting the reset button for mammals and clearing the playing field,” adds Farke.

TREE HUGGERS

Already in the Cretaceous there were numerous fluffy, feathered theropods scampering in the trees. Assuming that flowering plants continued to spread and thrive as they did in our history, then could primate-like dinosaurs have specialised to take advantage of the fruit they produced? Prof Matthew Bonnan, a palaeobiologist at Stockton University in New Jersey, argues that primates evolved large, forward-facing eyes with colour vision to forage for fruit.

“Is there a connection between being frugivorous [fruit-eating] and having a larger brain? We don’t know, but one could imagine arboreal dinosaurs that formed a co-evolutionary relationship with flowering plants by eating their fruits and dispersing the seeds,” he says. “Whether these fruit-eating dinosaurs would

have evolved complex social groups like primates is pure speculation.”

Other ecological spaces little explored by dinosaurs were aquatic environments. “In mammals we’ve seen a return to the sea, in several different iterations,” says Farke. “We’ve had things like whales and manatees that have gone back into the oceans, and things like otters that spend a lot of time in the water. It’s cool to think about what dinosaurs could have looked like if they’d gone in a cetacean direction.”

But if their giant marine reptile relatives – the mosasaurs and plesiosaurs – had survived, then dinosaurs might have found it hard to get a foothold.

There could also have been other consequences of dinosaurs and their reptilian relatives, such as the flying pterosaurs, not petering out at the end of the Cretaceous. Although birds co-existed with dinosaurs for a long time in the Cretaceous, their diversity was low compared to today. “Modern bird groups underwent an explosive radiation after the mass extinction, maybe because pterosaurs went extinct and opened up new niches,” says Dr Victoria Arbour, a palaeontologist at the ●

Certain dinosaurs might have gone back into the oceans, like the manatee did





● Royal Ontario Museum in Toronto. “Without the mass extinction, maybe birds wouldn’t be as diverse and successful as they are today, and maybe we wouldn’t have things like songbirds, parrots, hawks, or hummingbirds at all.”

Most experts seem to agree that the largest land mammals such as elephants, mammoths, giant relatives of rhinos and sloths, and perhaps even horses and giraffes, probably couldn’t have evolved if large dinosaurs had remained to occupy the niches they came to fill.

But perhaps smaller mammals such as rodents, bats and primates would have been just as successful. If that had been the case, then some of those primates

If dinosaurs had survived into the Ice Ages, could they have developed thick pelts like modern musk ox?

“If we speculate that humans had evolved alongside dinosaurs, then they probably would have been able to co-exist”

could have climbed down from the trees onto the grasslands and savannahs that eventually replaced the thick forests of the Cretaceous, and evolved into hominids, as our ancestors did.

“If we speculate that humans had evolved alongside dinosaurs, then they probably would have been able to co-exist,” says Farke. “Humans already evolved in ecosystems that had large land animals and predators. We probably would have done okay.”

“Unarmed, solitary humans are still easy targets for large predators like bears and lions,” agrees Arbour. “But overall humans are pretty good at surviving alongside large, dangerous animals.”

CENOZOIC EXTINCTION

Dinosaurs might not have been so lucky though, as humans seem to have a special skill for killing off large animals. Perhaps the biggest dinosaurs would have gone the way of the mammoth and the dodo. “Humans are really good at extinguishing megafauna – through hunting, climate change or habitat destruction,” Arbour says. “Dinosaurs in the 21st Century, just like modern animals, would probably have reduced populations and face the threat of extinction.”

Big dinosaurs would perhaps only persist in protected reserves, such as national parks and wildlife refuges – modern-day equivalents of *Jurassic Park*. ●

PHOTO: GETTY

DOMESTICATED DINOSAURS

Had dinosaurs survived, might we have used them for labour and food, or hunted them as trophies?



In the cartoon *The Flintstones*, Fred Flintstone works as a 'bronto crane operator', riding a sauropod that does the heavy lifting in a quarry. Yet it seems unlikely that we would ever have been able to persuade dinosaurs to work for us in agrarian societies – as humans did with oxen and horses. "Given the brainpower of some of these dinosaurs, I can't imagine that a lot of them would be in the realm of things that would domesticate easily," says palaeontologist Dr Andy Farke.

But there may have been other ways that humans could have exploited dinosaurs.

"Animals that have been domesticated by humans are often those that have group

social structures like wolves, caribou and cattle," says palaeontologist Dr Victoria Arbour. "For dinosaurs, herding species like ceratopsians and hadrosaurs might have been good candidates for cattle analogues. There's less evidence for social behaviour in small carnivores, but perhaps some little predatory, feathery theropods might have filled the spots in our homes reserved for dogs and cats today."

Had we exploited some of these larger herbivores to toil in our fields, then surely we would have hunted and farmed some for meat too? This begs the question: what would dinosaur meat have tasted like? Of course, if you eat chicken or

turkey today, then you are already eating theropod dinosaur, but the flesh of these sedentary domesticated creatures is a poor analogy for *T. rex* meat – a better one might be emu or ostrich, which is packed with lean muscle due to the animals' sprinting abilities.

"Just as with modern farming there'd probably be the whole thing with wanting to get organically raised or free-range dinosaur meat – or corn-fed *Triceratops*," quips Farke.

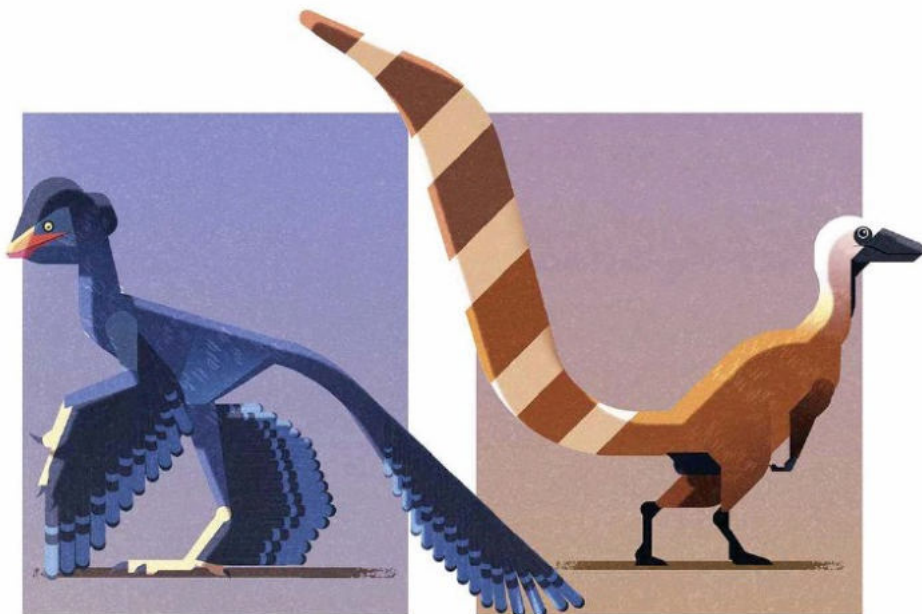
Ostriches are farmed today, so some of the fast, ostrich-like ornithomimid dinosaurs, such as *Gallimimus* (famous from the stampede scene in *Jurassic Park*), could have populated ranches in the same way.

Battery farms of egg-laying dinosaurs could also have been a possibility. "The glorious thing about dinosaurs is that they grew very quickly," says Farke.

Today, there are certain types of wealthy gun-lovers who will pay significant sums of money to shoot lions, rhinos and giraffes on private game reserves. Therefore, had dinosaurs survived to the present, then they would surely be the ultimate in big game. Horned dinosaurs, duckbills and even carnivores like *T. rex* could have been targets, argues Arbour. "Big ceratopsians, hadrosaurs and theropods would probably be highly sought after for trophy hunting," she says.

JURASSIC BARK?

A *T. rex* would probably make a terrible house pet (just think of the litter tray!). But could some smaller species have made more fitting companions?



Microraptor

Dark and iridescent plumage, with large flight feathers on its hind and forelimbs. Likes to preen, nap and observe everything with its hawk-like watchful eyes.

SIZE: One of the tiniest dinos at less than 1kg in weight and about 80cm in length.

PROS: Has four wings of awesomeness. It's intelligent and responds well to commands.

CONS: Can attempt to disembowel the cat with its sickle-shaped second claw; requires falconry hood during initial training.

Sinosauropteryx

The first known feathered dinosaur, discovered in 1996. Has fluffy ginger plumage and enjoys scratches and strokes. Likes to chase toys in lieu of fast-moving prey.

SIZE: A metre in length, including the long tail. But it's very dainty, weighing just 0.5kg.

PROS: Loves to snuggle. Has fetching ginger-and-white tail stripes.

CONS: Can be neurotic and restless, and requires frequent exercise.

• Smaller dinosaurs that infringed on crops or livestock would probably be hunted as 'nuisance' animals, as wolves and dingoes are today, adds Arbour. "It would be really hard for large sauropods to survive alongside us. They're so big and would require so much food, that I doubt we could set aside enough wild spaces for them to thrive."

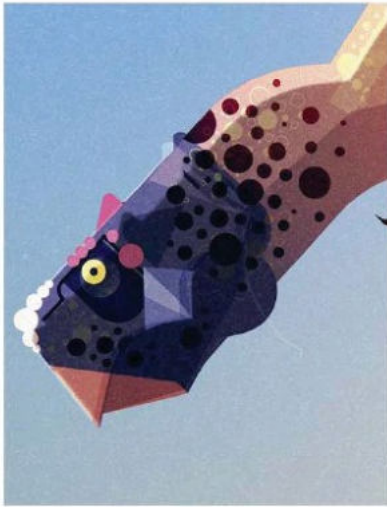
CITY DWELLERS

The dinosaurs that might do particularly well in the modern era are those that could learn to live and thrive alongside people. In our world today, the vast majority of animal biomass is made up of the species that we farm or have domesticated, or those that live around our cities and developments – and so it would also have been in a reality where humans and dinosaurs co-existed. There might have been dinosaur equivalents of seagulls, pigeons, rats, raccoons and foxes – all very well adapted to take advantage of the resources available in urban environments.

"Small, scrappy dinosaurs might have been able to eke out a living on the margins of housing devel-

If all the dinosaurs had survived, their descendants could have given Mr Seagull some competition for your chips





Psittacosaurus

This parrot-beaked herbivore would make a good pet. It lives in herds in the wild, so it's highly sociable and has a fairly gentle temperament.

SIZE: Up to 2m in length and 20kg in weight – about the same as a medium-sized dog.

PROS: Has fluffy tail bristles and cute facial horns; helps to keep the lawn tidy by mowing grass with beak.

CONS: Has an unfortunate tendency to gnaw the furnishings.



Yi qi

This teeny, pigeon-sized tree-dweller is the only dinosaur known to have adopted a bat method of flight. Has wings formed of skin membranes, but also tight, downy plumage and four pretty, ribbon-like tail feathers.

SIZE: Positively minute for a dinosaur at 80cm in length and just 380g in weight.

PROS: Small, with short, dense feathers so it doesn't shed much around the house.

CONS: Prone to screechiness; needs large aviary to glide back and forth within.



Compsognathus

The smallest known dinosaur until the 1990s when a variety of dainty, feathered relatives began to turn up in China. Lightly built, so great for small apartments.

SIZE: Turkey-sized but much lighter. It's up to 1m in length but just 3kg in weight.

PROS: Smaller size makes it an ideal lap-dinosaur; it lives in packs so is highly social.

CONS: Needs constant supply of small, live lizards to snack upon; bit of a finger nibbler.

“Without the dinosaurs disappearing, mammals would not have had the same opportunity”

opments,” suggests Farke. You can just imagine little beaked herbivorous dinosaurs nibbling at the roses and hydrangeas in your garden.

“Animals that do well in urban environments today tend to be those that are good at eating whatever we're throwing away, and making use of the structures we build,” agrees Arbour. “Small omnivorous or predatory theropods would perhaps have been lurking around garbage cans.”

Obviously, we might have domesticated dinosaurs to exploit for meat and eggs or agricultural labour,

and we would very likely have taken them into our homes as pets – the feathery or scaly equivalents of dogs and cats.

Perhaps, though, the idea that humans could have evolved in a world filled with dinosaurs is simply too far-fetched. “I have no doubt that we would not be here,” says Brusatte. “The asteroid was one of those dominoes that set in motion a chain of events that led to us. Without the dinosaurs disappearing, mammals would not have had the same opportunity.”

He argues that mammals had already existed with dinosaurs for 160 million years or more when the asteroid struck. But they were mostly “marginal, shadowy little creatures” and – had the asteroid not caused a mass extinction – would likely remain that way today.

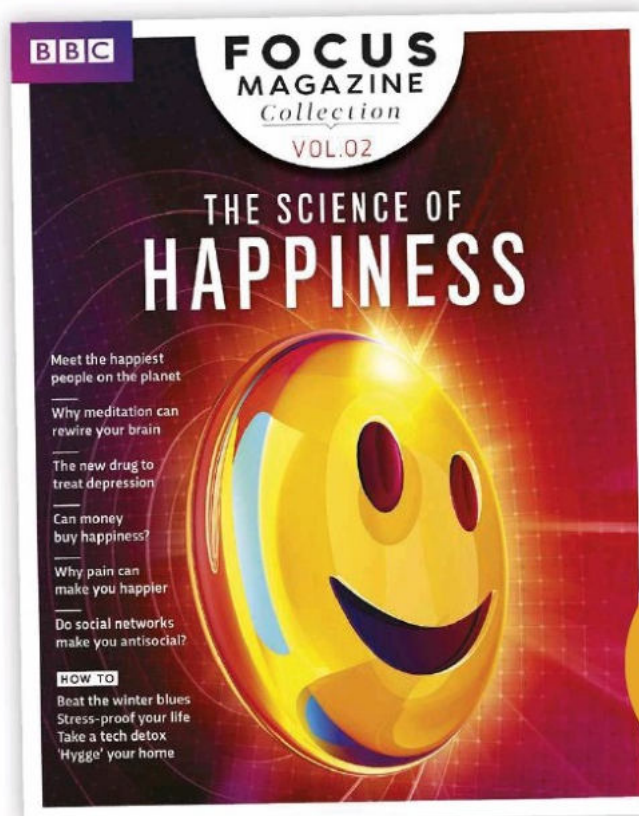
As Brusatte points out: “What's another 66 million years when it had already been like that for 160 million years already.”

John Pickrell is a science journalist, and author of *Flying Dinosaurs*. He tweets from @john_pickrell

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A photograph of a brown and black rabbit standing on its hind legs, looking upwards and to the right. The rabbit is positioned in the center of the frame, with its body angled slightly towards the left. The background is a solid black, which makes the rabbit stand out. The rabbit's fur is a mix of brown and black, with some white markings on its face and chest. Its ears are long and floppy. The overall mood is contemplative and serious.

CAN WE END ANIMAL TESTING?

We find out whether innovative techniques using stem cells, computer modelling and 3D-printing could reduce the number of animals used in medical research

WORDS: ALLA KATSNELSON

There are many disagreements in the world of research, but few debates will get as heated as those surrounding animal testing. Many scientists and research advocates contend that animal experiments are crucial for learning about basic biology and disease mechanisms, and are necessary for testing the safety and efficacy of new medicines and chemicals. They point to many potent medicines that exist thanks to animal testing. Opponents, meanwhile, contend that subjecting animals to experiments for human gain is ethically unjustified. What's more, many argue, such research is often misleading because it compares apples and oranges: results from animal studies often don't translate to humans because the animals are just too different.

NEW METHODS

Animal welfare activists have long insisted that researchers jettison research on animals for alternative methods, such as human stem cells grown in a dish, computer modeling, or expanded clinical trials. But it's only in the past few years that most of these tools have become truly good enough for prime-time use. Now, many researchers are embracing these alternatives. As Dr Donald Ingber, director of Harvard University's Wyss Institute for Biologically Inspired Engineering, says,

"ANIMAL TESTING IS AN IMPORTANT TOOL, BUT AT THE SAME TIME IT HAS OFTEN BEEN MISLEADING"

"It's coming to a tipping point."

Tallying the precise number of animals used in research is difficult, because countries record animal experiments differently. But estimates suggest that the count is more than 100 million animals each year worldwide. The major-

ity are used in basic research and breeding to create specific genetic modifications. A smaller percentage of animals are used to test the effects of drugs or chemicals. More than 95 per cent of all animals used in research are mice, rats, birds and fish, but other species enter the mix, too. For example, some 60,000 monkeys like macaques are used in experiments in the US, Europe and Australia.

It's hard to deny that research on animals has advanced human health. In the 19th Century, for example, French biologist Louis Pasteur used animal experiments to understand how microorganisms can cause disease, and later to develop a vaccine for rabies. Animal studies were also crucial in understanding how insulin is produced and in developing ways to supplement it in people with diabetes. Penicillin was proven effective in mice, blood transfusions were perfected in rabbits, and kidney transplants were tested in dogs and pigs.

There's no shortage of recent examples, either. Experiments in which macaques were infected with SIV, the monkey version of the AIDS-causing HIV virus, were crucial in creating antiretroviral medicines and in developing strategies for a potential HIV vaccine.

LEFT: A researcher tests the effects of ultra-high frequency radiation on a rabbit in the 1980s





LEFT: This ear was created using a 3D printer by Prof Anthony Atala at Wake Forest Institute for Regenerative Medicine. Once it's been implanted, it develops functional tissue and blood vessels, so could be used to replace diseased or damaged tissue in patients. The team used the same technology to create bone and muscle, on which to test novel treatments

BELOW: Stem cells, which can be used in medical testing, can be harvested from young human embryos, like the one pictured here on the end of a needle

Deep brain stimulation, used by some 20,000 people with Parkinson's disease, relied on rat and monkey models to understand how the disease affects a part of the brain called the basal ganglia and how surgically implanting a stimulator could improve patients' motor symptoms. And brain-machine interfaces that allow paralysed people to perform everyday tasks, such as bringing a coffee cup to their lips, are being developed with the help of experiments in monkeys.

A DYING BREED?

Yet many scientists would now agree that for some studies, animal experiments are no longer the best way forward. "Animal testing is an important tool – it has made our world safer and it has helped to develop certain drugs – but at the same time it has very often been misleading," says Prof Thomas Hartung, a toxicologist and the director of the Center for Alternatives to Animal Testing at Johns Hopkins University in Baltimore, Maryland. He says that in just the past few years, there has been more agreement on the limitations of animal testing and "the belief that this is some type of gold standard is fading".

Among researchers and the public, support for limiting animal research where possible seems to be growing. In the past few years, the European Union, Israel and India have banned animal testing for cosmetics, and other countries are considering similar laws. (The UK led the way with the first such ban back in 1989.) Countries throughout the world have largely phased out research on Old World primates such as chimpanzees, and in many regions the use of other non-human primates – as well as some other mammalian species – is also on the decline. Meanwhile, regulatory bodies like the US Food and

WHY DO WE STILL TEST ON ANIMALS?

No matter how good the alternatives to animal testing get, it's unlikely to be eradicated. "There are certain things you cannot easily test without animals," says toxicologist Prof Thomas Hartung. This includes studies on psychiatric disorders in which tracking a behavioural change is important, or studies of conditions where regions of a particular organ are affected differently, such as tuberculosis. And even though stem cell technologies are improving fast, they still have some major limitations. Some cell types that are important in disease are difficult to produce, for example.

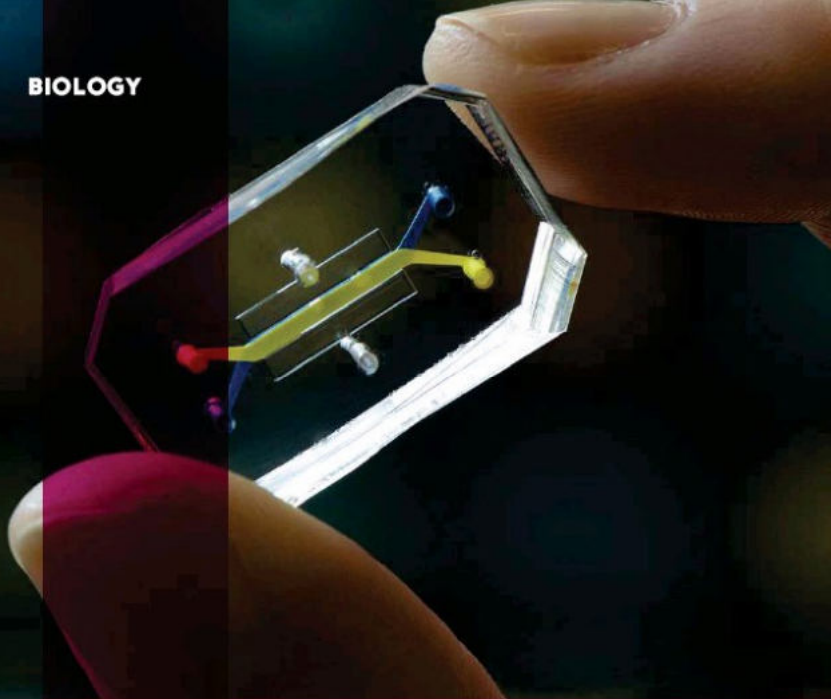
And even linking up human stem cell models representing several organs doesn't reveal a drug's response to a living, breathing organism. These systems are simply not well-enough developed for wide-scale use. "In the end, our quest is to give the right answer regarding a medicine's safety and efficacy," says Roche Pharmaceuticals' Thomas Singer. "We are agnostic as to whether an animal model or an alternative model would be best."

One hold-up in moving to alternatives is the fact that countries have different rules for when or whether animal tests are needed for a product to be sold. Even if a cell culture test for a certain pesticide has been accepted in one country as better than an older animal test, companies that plan to sell it in countries where this test is not accepted must do the animal tests. "You can develop a [non-animal] method, get it validated, and get it

used, in every country but one," says Dr Amy Clippinger, associate director of PETA's International Science Consortium. "And if companies want to sell in that country, you will see no reduction in animal use."

For such regulatory matters, says Hartung, decreasing animal use will to some extent depend on a changing of the guard. "There are still too many people who overestimate the value of animal tests," he says. "Some things will change one retirement at a time."



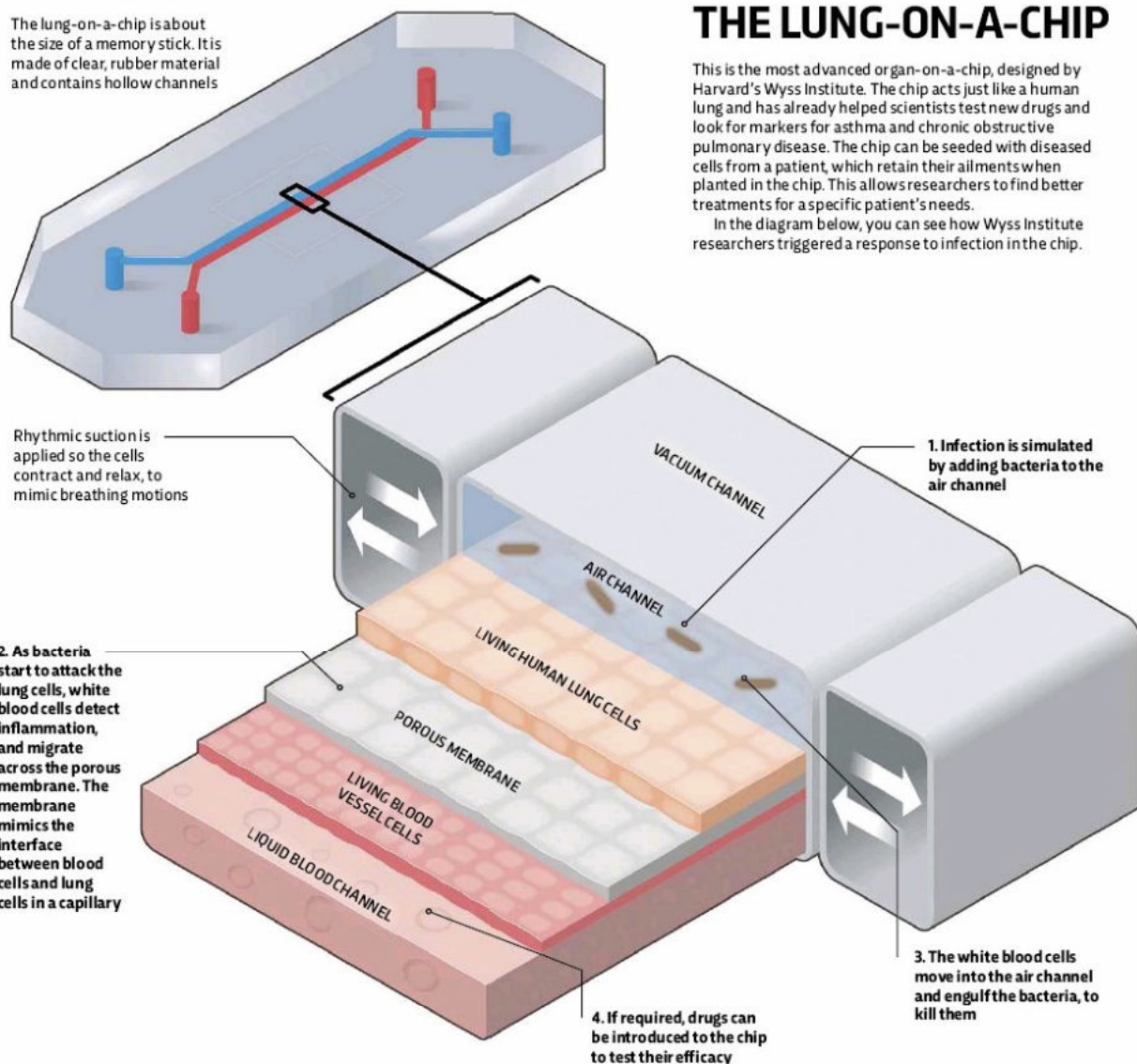


● Drug Administration (FDA), which have long insisted on animal studies, are beginning to evaluate whether alternative technologies can show similar or better results, says Ingber, and companies are trying to implement these tools into their pipeline.

CHANGING TIMES

It's not just ethical concerns spurring this change. Switching to studies that use human tissue instead of animals may often make for better science. Experimental medicines that seem to be effective in animals (usually rodents) often fail in human trials; 9 out of 10 cancer drugs, and 98 out of 100 neurological and psychiatric drugs that show promise in animal

The lung-on-a-chip is about the size of a memory stick. It is made of clear, rubber material and contains hollow channels



tests don't turn out to work when tested in humans. Animal studies certainly don't deserve the full blame for this disconnect, but finding better and more predictive disease models might help, researchers say.

There are also cases where a human disease simply can't be modelled in animals. For example, Alysson Muotri, a neuroscientist at the University of California, San Diego, studies a rare but devastating neurological disease called Aicardi-Goutieres Syndrome (AGS). The mutations causing AGS are well-known, but when Muotri studied mice that had been genetically engineered to carry these mutations, he found that they had no symptoms. When his team grew cell structures called organoids from stem cells derived from tissues of patients with the disease, they recreated the nerve cells' glitch. They learned that what causes the disease is an immune response to an element of DNA that is specific to humans. "It's a case where we have a truly human disorder," Muotri says. "We couldn't see it in the mouse, and very likely we wouldn't see it in a primate."

One especially promising human cell-based alternative to animal research is so-called 'organ-on-a-chip' technology, in which specific types of human stem cells are grown with membranes on a microchip to mimic the function of specific organs. "There are lots of things you can do on these chips that you can't do in animal testing," says Ingber, who has developed about 15 such devices, along with his colleagues, for mimicking the function of organs including the lungs, intestine, kidney and bone marrow. Each chip, the size of a computer memory stick, is engraved with tiny channels that are lined with human cells and artificial blood vessel tissue. The tools also capture physiological features such as blood pressure and mechanical forces that act on cells. Researchers can link up to 10 chips together with vascular channels containing human blood in order to study how organ systems interact.

"We've been able to mimic amazing things – diseases of all types, pulmonary oedema, asthma, chronic obstructive pulmonary disease, inflammatory bowel disease, viral infection, drug toxicities – and we've been able to make chips with cells from patients," Ingber says. These devices reveal drug toxicities that don't show up in animal models, and can also probe questions that can't be asked in clinical trials for ethical reasons. His team is using them to model the effects of radiation exposure, as well as childhood illnesses and malnutrition.

But organs-on-a-chip aren't just for university scientists. Roche Pharmaceuticals, one of the top five drug companies worldwide, embraced the technology three years ago and already uses it to test the safety of new compounds. "It opens a totally new field of opportunities to us in biology and drug discovery, and all of them are much better than an animal ever can be," says Thomas Singer, Roche's global

head of pharmaceutical sciences. As this and other tools improve further, more companies have adopted them, banking on them being more reproducible and predictable than animal tests. "In the beginning we were very much on our own," Singer says. "But I am convinced this technology will see a huge boost in development."

"THERE ARE LOTS OF THINGS YOU CAN DO ON THESE CHIPS THAT YOU CAN'T DO IN ANIMAL TESTING"

TINY ORGANS

Other human cell-based alternatives to animal models are becoming available too. Prof Anthony Atala, director of the Wake Forest Institute for Regenerative Medicine in North Carolina, is creating tissues and organs such as bladders and kidneys using a 3D printer that spits out different types of human cells. "You are miniaturising a human organ, really," he says. Initially, his team built these organs for surgical use in the body, but he soon realised that they could be standardised and mass-produced in minutes – ideal specs for screening new medicines and testing their safety. Initially, he says, such technologies will just supplement the animal studies, but eventually they can replace them.

Toxicology studies, for medicines as well as for all sorts of other chemicals, are a low-hanging fruit for switching to alternative methods, explains Hartung. Many animal tests are particularly bad at predicting toxicity in humans, not to mention slow and expensive to conduct, and in many cases, more modern, cell- or computer-based assays have been developed. Pushing the issue, a European law passed a decade ago requires thousands of chemicals to be assessed for safety. Hartung and other toxicologists in academia and industry have developed a computer model that can predict the toxicity of a compound based on its similarity to others. "This is astonishingly powerful," he says.

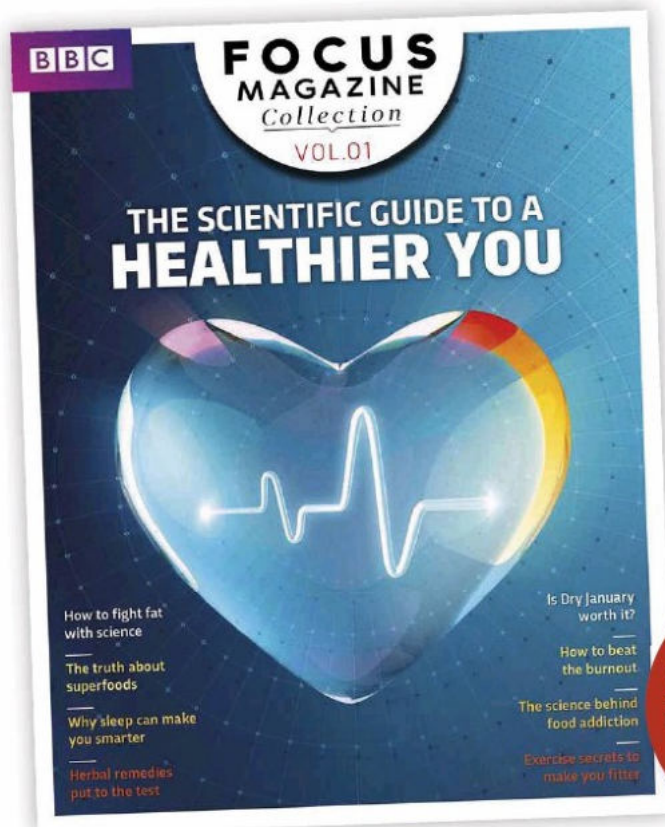
But despite the promise of all these techniques, experts say, change will probably come slowly, and it's likely that some forms of animal models will never be eliminated at all. As Ingber puts it, "I think we are going to replace animal testing one model at a time." ●

Alla Katsnelson is a science writer and editor with a PhD in mammalian brain development.

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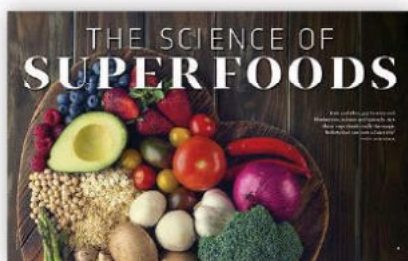
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HELEN CZERSKI ON... **FROST**

***"THERE ARE CLEAR AND FROSTY MORNINGS,
WHEN THE OUTSIDE WORLD HAS TRANSFORMED
ITSELF INTO A TWINKLING DISNEY SET"***

The weather at the moment is a bit grim: grey and cold with a generous dash of sleet. But there are clear and frosty mornings that make up for it, when the outside world has transformed itself into a twinkling Disney set. Yet when you look at the frost, it isn't evenly distributed. Plants and wooden benches are often covered in it, but metal railings and the patches of ground beneath trees aren't. It looks as though frost is an indicator for something, but what is it?

The beauty of frost comes from the moment of its formation. When we think of water cooling, we tend to assume that water vapour will condense to form liquid water, which will then freeze to form ice. But frost is assembled from thin air and bypasses the middle stage completely. Molecules of water in the air bump into an ice crystal and just freeze directly onto it, dropping into place on the existing crystal structure. It turns out that a floating water molecule is more likely to join the frozen crowd if there's a space for it on a rough surface, so lumps and bumps get filled in and nice, smooth crystalline facets form. But that doesn't answer the question about where frost is most likely to happen.

For frost to form, a solid surface needs to be below 0°C, and there needs to be sufficient water in the air. When it's close to freezing, the air is generally very dry already, but if there are more than five water molecules in every thousand air molecules, the air is officially supersaturated, and frost can be water's route out. This is part of the puzzle – pockets of cold, humid air are where you will find frost. For example, some dark



surfaces radiate their heat away quickly, and so they will cool more than their surroundings, dropping below the temperature needed for frost. This explains why there's often a frost-free patch under a tree. The tree is insulating the ground around it, preventing the soil from dropping below the critical temperature.

But there's one extra condition for frost formation. Even if the temperature and humidity are right, frost may still not form. And that's because, for that first floating water molecule to freeze when it bumps into a solid surface, that surface has to have the right structure for it to lock on to. If there's already ice there, that's perfect – the new molecule can just slot into its place in the ice crystal. If not, you need a nucleus. This is a starting point that provides the right structure, like a flat Lego baseplate that lets you position the first bricks. Plants are often beautifully frosted because bacteria on their surface play the nucleus role. There are a few types of bacteria that do this, and they're extremely common. Without this coating of biological ice nuclei, plants would stay frost-free to lower temperatures. But nature is full of bacteria, and frosted lawns and hedges are the result.

So that cheerful frosty morning can be appreciated on two levels. There's the white sparkle itself, and there are the invisible patterns of temperature, humidity and ice nuclei that are revealed in the twinkling. But frost appreciation is a chilly hobby, and the sort of thing that earns you a hot drink when you get back inside. Brrr! **G**

Dr Helen Czerski is a physicist and BBC presenter. Her new series on temperature is out this month.

NEXT ISSUE: COCOA POWDER

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astrophysicist



ALEX FRANKLIN-CHEUNG
Environment/
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DR PETER J BENTLEY
Computer
scientist, author



PROF ALICE GREGORY
Psychologist,
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science writer



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science writer



EMMA DAVIES
Health expert,
science writer



LUIS VILLAZON
Science/tech
writer



DR AARATHI PRASAD
Biologist,
geneticist



PROF ROBERT MATTHEWS
Physicist,
science writer

YOUR QUESTIONS ANSWERED

FEBRUARY 2018

EDITED BY JAMES LLOYD

Why is air invisible?

BRITTNEY W'S GRADE 2 CLASS, VIA TWITTER

Air is made up mostly of nitrogen and oxygen molecules that are spread too thinly to affect light noticeably by, say, altering its colour or intensity. Even so, air's presence is revealed in hot weather through the shimmering effect called 'heat haze'. This is the result of the heat causing fluctuations in the density of the air, which in turn affects its optical properties. **RM**

PHOTO: GETTY





Why do oysters make pearls?

SUSAN BRAGG, BARNSTAPLE

It's an immune response designed to protect the oyster from a parasite or an injury (not just a grain of sand as is commonly believed). Cells from the mantle of the oyster form a pearl sac around the irritation. The pearl sac then secretes calcium carbonate and conchiolin protein that builds up in layers to form an impermeable barrier. **LV**

Can you melt wood?

CHARLIE SMITH, VIA EMAIL



No. Wood is mostly cellulose, lignin and water. If you heat wood, the water boils away first and then the lignin and cellulose (both long-chain organic molecules) will react with oxygen and burn. Even in a vacuum, these molecular chains are too long and tangled to wiggle free into the liquid phase before they reach temperatures high enough to break their bonds. Instead they break down into smaller substances, like methane and organic compounds containing carbon and hydrogen. **RM**

IN NUMBERS

17

The number of named storms in 2017.

99.95

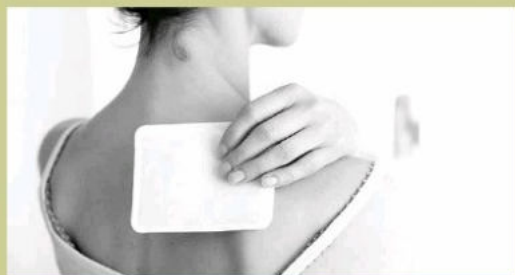
The percentage of light absorbed by black feathers on birds of paradise. This rivals Vantablack, the darkest material on Earth.

99

The percentage of green sea turtles being born female on the northern Great Barrier Reef.

Do heat patches really help with muscle pain?

JASON ORBEN, USA



Although heat should not be used for a fresh injury, it can certainly be beneficial for long-term conditions. Heat patches dilate blood vessels, promoting blood flow and helping to relax painful muscles. Tissue injury activates nerve endings in the skin called nociceptors, which transmit signals to the brain to inform it of pain. At the same time, neurotransmitters initiate a reflex that causes muscles to contract at the injury site, often to the point of spasm. Fortunately, heat can activate temperature-sensitive thermoreceptors, which initiate nerve signals to block those from nociceptors. Applying pressure also helps, by triggering nerve endings called proprioceptors. Activating the sets of receptors helps painful muscles to relax. **ED**



Is it possible to sleep with your eyes open?

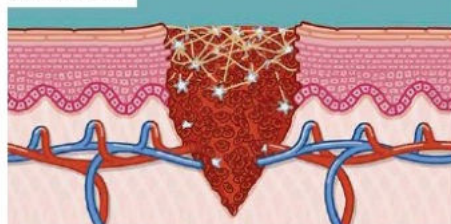
RICHARD KIM, VIA EMAIL

Not normally, but there is a condition called nocturnal lagophthalmos where a sufferer is unable to shut their eyelids when asleep. According to one review, this occurs in up to 5 per cent of adults. This can be due to a variety of factors, including protruding eyes or abnormalities of the eyelids. There are also cases in which the cause has not been established. Nocturnal lagophthalmos can lead to certain difficulties, from sore eyes to more severe problems such as the development of ulcers on the cornea. Do talk to your doctor if you are waking up with red or sore eyes or have been told by someone that you sleep with your eyes open. **AGR**

...WHEN I GET A CUT?

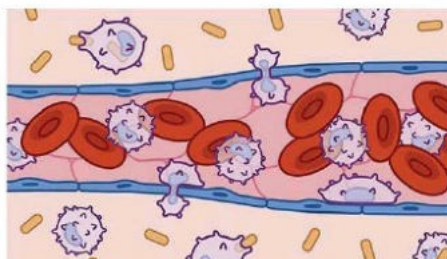
Your skin's most important job is to keep out the billions of harmful bacteria that swarm over every surface. Any wound that penetrates the dermis layer and causes bleeding will allow bacteria to get in, so we have evolved a precisely coordinated mechanism to seal up the gap as quickly as possible. The healing process uses extra collagen protein for the repair, so the new skin is actually stronger than before. This shows as a visible scar.

SMALL CUT



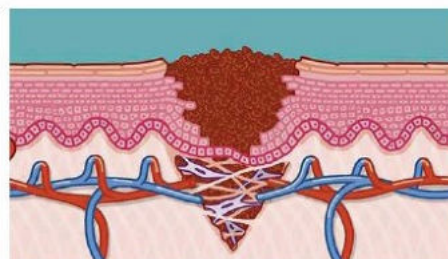
1. Haemostasis

When the skin is punctured, blood vessels contract and platelets release fibrin proteins that tangle together to form a clot and seal the wound.



2. Inflammation

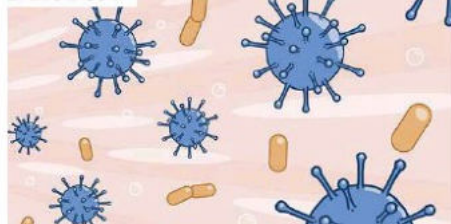
Next the blood vessels expand again to allow white blood cells to flock to the wound site. These attack any bacteria that got past the clot.



3. Proliferation

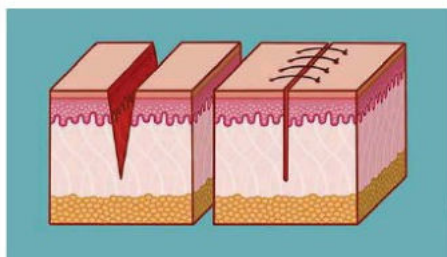
After a few days, fibroblast cells arrive and produce collagen. This protein acts like a scaffold, while the dermis cells reproduce to close up the wound.

LARGE CUT



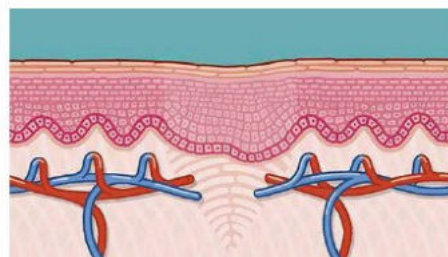
1. Keep it clean

Wash the open cut to prevent bacteria getting trapped inside. Don't use disinfectant because this will kill your own cells that are trying to repair the wound.



2. Seal it

A plaster keeps dirt out and helps the clot form. If the wound is still bleeding after 10 minutes with a plaster on, you may need stitches.



3. Scarring

The skin continually rebuilds the collagen matrix for up to a year after the cut. This scar tissue will fade slightly for another year after that.



Why do dogs wag their tails?

JOE GOODMAN, VIAEMAIL

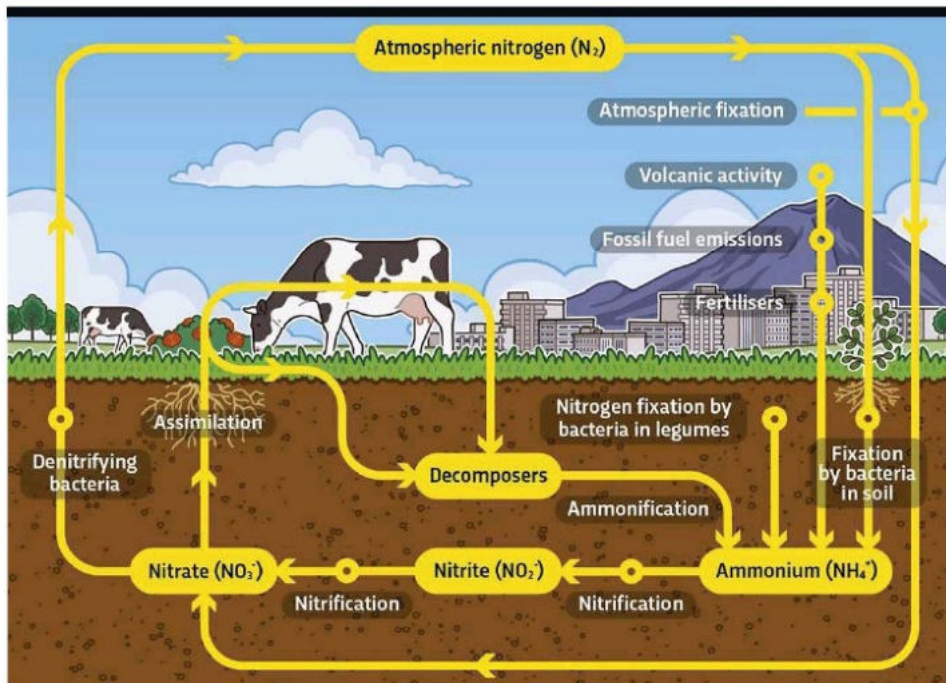
Dogs 'talk' with their tails. The position of the tail can tell us a lot about how a dog is feeling; hung low suggests fear and submission, whereas held high is a sign of dominance and arousal. A wagging tail often conveys happiness and excitement but neuroscientists at the University of Trento in Italy have found that the speed and direction of wag is important in ascertaining if the dog is either negatively (slow and to the left) or positively (fast and to the right) stimulated. cc

Does a cup of tea cool quicker if it's stirred?

ADRIAN SINCLAIR, WILTSHIRE

Yes, but not enough to make it worth doing. A metal spoon in a cup of tea will act as a radiator, conducting heat to the air. If you stir it as well, you are bringing the hotter liquid from the centre of the cup to the edges, where it can cool faster. But experiments have shown that stirring a cuppa continuously for 10 minutes will only drop the temperature by 2°C, compared with just leaving it to stand. The fastest way to cool your tea down is to add a bit more milk, or a splash of cold water. lv





Where does the nitrogen in the air come from?

TIM BRIAN, VIA EMAIL

Nitrogen makes up 78 per cent of the air we breathe, and it's thought that most of it was initially trapped in the chunks of primordial rubble that formed the Earth. When they smashed together, they coalesced and their nitrogen content has been seeping out along the molten cracks in the planet's crust ever since. Nitrogen can only be used by living organisms after it has been 'fixed' into more reactive

compounds such as ammonia or oxides of nitrogen. Nitrogen fixation is carried out by bacteria, algae and human activity, and once organisms have benefited from it, some of the nitrogen compounds break down and go back into the atmosphere as nitrogen gas. Along with top-ups from volcanic eruptions, the 'nitrogen cycle' has kept the level pretty constant for at least 100 million years. **RM**



Why do we get dizzy when we spin?

MATT PATTINSON, DEVON

When you move your head, the acceleration is detected by hairs lining the side of fluid-filled tubes in your inner ear. If you spin for long enough, the brain gets desensitised to the constant turn signals

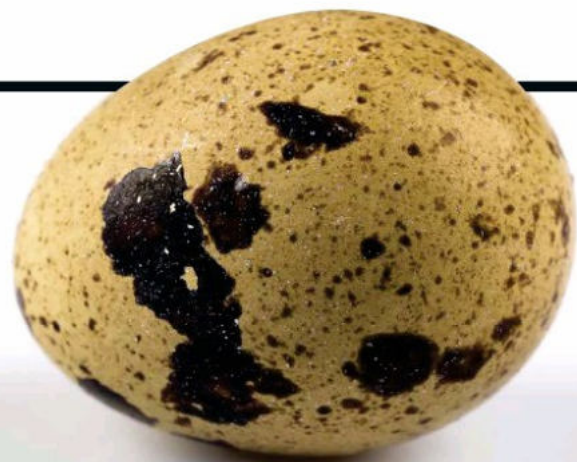
from your ear, and adjusts to zero them out. When you stop, the ears correctly report zero turning, but your brain is still actively cancelling this out and so it thinks you are now spinning in the opposite direction. **LV**

The ESO Very Large Telescope is located in the Atacama Desert, Chile

How large a telescope was needed to image an exoplanet?

EDWARD SEYMOUR, HOVE

The first-ever image of a planet beyond the Solar System was taken in 2005 by astronomers using the European Southern Observatory's Very Large Telescope (VLT) in Chile. Known as 2M1207b, the planet is about 1.5 times bigger than Jupiter and around 170 light-years away. It was detected using one of the VLT's four gigantic telescopes, whose light-gathering mirrors are an impressive 8.2 metres across. **RM**



JOHNATHAN HOLMES, BRISTOL

A collection of various pills and capsules in different colors (white, yellow, blue, red, pink) scattered on a black background.

JEROME WRIGHT, NORWICH

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How does trophy hunting affect wild animal populations?

STEVEN WHITE, BROMLEY

Since the days of the Roman Empire, wild animals have been slaughtered to prove power and wealth. Bigger is better when it comes to this 'sport', which means that dominant, mature male rhinos, elephants, lions, leopards and other animals are the prime targets of hunters. The artificially premature loss of strong, healthy individuals takes vital genes out of the breeding pool which, over time, can result

in an overall decline in body size and, where applicable, also horn or tusk size. Removing these frontline animals also undermines social cohesion and can leave members of prides and herds vulnerable to attack by other members of their own species. Although some argue that money from trophy hunting can help with conservation, there is not enough evidence to convince us that it can. **cc**



How thick is the thickest fog?

NINA CUNNINGHAM, OXFORDSHIRE

By definition, fog has a visibility of less than 1km, but it can get much thicker than that. The Met Office visibility scale runs down to a Category X fog, where visibility is less than 20m. If fog gets mixed with industrial pollution, it becomes smog and can be thicker still. During the Great Smog of 1952, drivers couldn't see their own headlights! **lv**

By weight, which animal has the largest baby relative to body size?

EMILY CANE, NEWCASTLE

Despite a kiwi being about the size of a chicken, the female lays an egg that is about half her weight! It's so big because it has an enormous yolk, which sustains the chick for the first

week of its life. Here you can see some other animals that have enormous babies, as well as those that have teeny tiny offspring (with humans thrown in for good measure). **lv**



Kiwi (egg)
(1/2)



Giraffe
(1/10)



Beluga whale
(1/17)



Human
(1/22)



Elephant
(1/26)



Giant clam
(1/500,000,000)



Ocean sunfish
(1/1,500,000)




Red kangaroo
(1/100,000)



Honey possum
(1/2,400)



Giant panda
(1/900)



WHAT IS THIS?

Wahweap Hoodoos

Nope, these aren't weird, oversized toadstools. They are a group of rock structures called 'hoodoos', which started forming more than 100 million years ago. The columns, which are located in Utah's Grand Staircase-Escalante National Monument, are made of soft white sandstone that has slowly eroded away over the years, leaving caps consisting of a type of harder brown sandstone.

WHO REALLY INVENTED?

THE MRI MACHINE



PETER MANSFIELD
PAUL LAUTERBUR

RAYMOND
DAMADIAN

With its ability to image the internal organs and functioning of the body without using X-rays, magnetic resonance imaging (MRI) ranks as one of the biggest medical breakthroughs, and its development led to a Nobel Prize in 2003 for two scientists: Paul Lauterbur of the State University of New York and Peter Mansfield of the University of Nottingham. But within a month of the prize being announced, a full-page advert appeared in *The New York Times* insisting MRI was actually invented by a New York doctor named Raymond Damadian.

MRI exploits so-called nuclear magnetic resonance (NMR) in which hydrogen nuclei in our bodies are first gripped by powerful magnetic fields, then stimulated into producing radio waves. As these signals are affected by the nature of the tissue, Damadian was among those who thought NMR might help with the early detection of cancer. By the early 1970s the idea had shown promise, and Damadian was granted a patent for this use of NMR. However, others were already going further, and trying to create clear visual images from the signals. Lauterbur and Mansfield are widely regarded to have carried out the most work towards solving the extremely challenging technical issues involved, turning MRI into the versatile technique it is today. **RM**



Are any dog breeds close to becoming a new species?

PHILLIP HOGG, VIA EMAIL

In a word, 'no'. Domestic dogs evolved between 17,000-33,000 years ago. Most 'breeds', which have been artificially selected by humans, have arisen very recently within the last 200 years. Visually, a Chihuahua is the chalk to a Great Dane's cheese, yet they are still the same species, *Canis lupus familiaris*, and are direct descendants of the grey wolf. All domestic dog breeds are able to interbreed to give

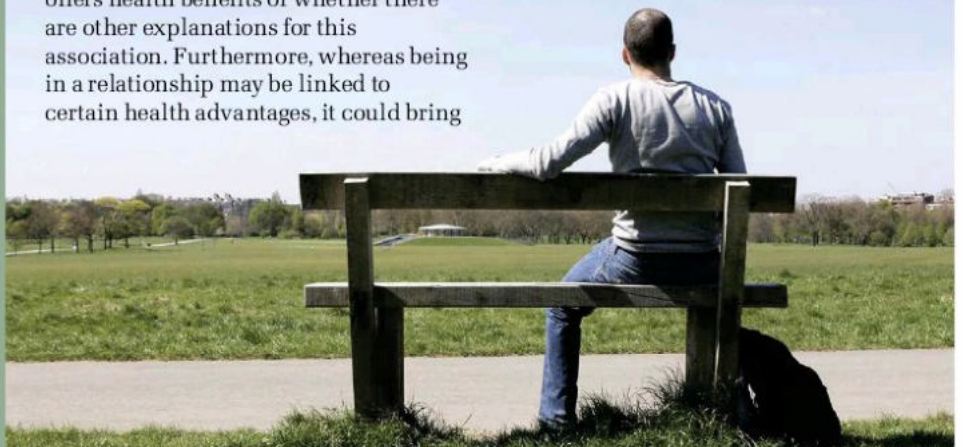
birth to reproductively viable offspring. This is because their genomes remain relatively unchanged, despite their physical characteristics appearing so different. This key evidence tells us that various dog breeds are not in the running to become a new species any time soon. It takes a long time for mutations, which cause inheritable changes to characteristics, to arise within populations. **cc**

Is being single bad for your health?

PAUL EVANS, BARKING

It is sometimes argued that being in a relationship can offer health benefits. The research cited in support of this argument says that those who are married are on average healthier than those who are not. However, the situation is likely to be much more complex than this. For example, it is not clear whether being in a relationship offers health benefits or whether there are other explanations for this association. Furthermore, whereas being in a relationship may be linked to certain health advantages, it could bring

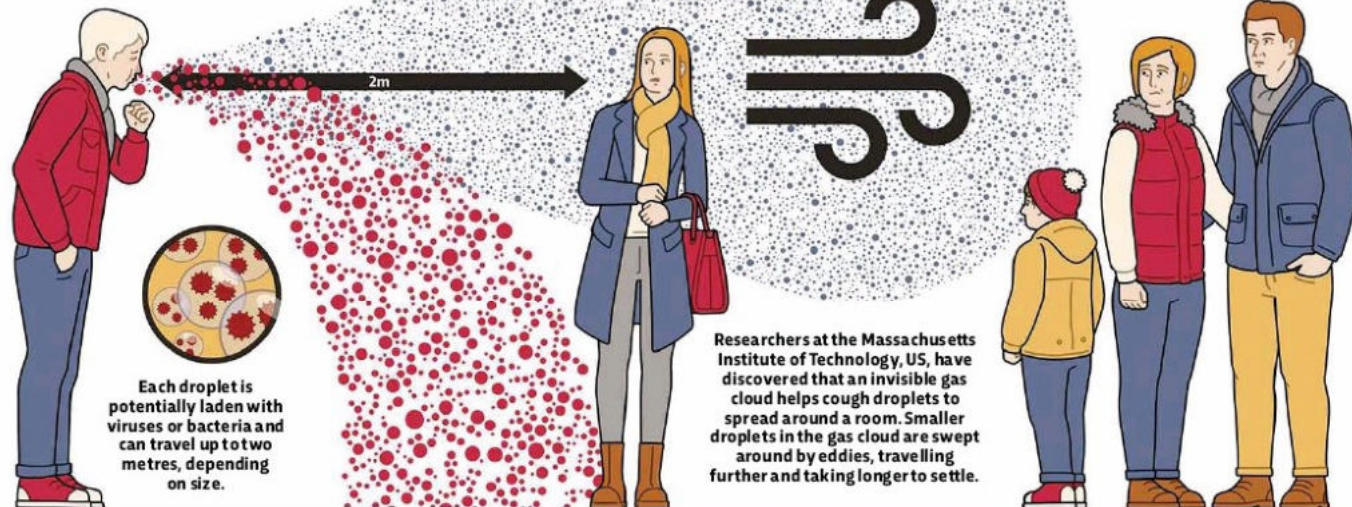
health risks too. Research suggests, for example, that people who are married are more likely to be overweight than those who are not. Finally, one size does not fit all. Whereas being in a happy relationship may bring certain advantages, being in a dysfunctional one is unlikely to do so. **AGr**



How far do germs travel when we cough?

MISTY, INDIA

Powered by the diaphragm, abdominal and rib muscles, coughing is highly effective at clearing irritants or mucus from the lungs. Each cough expels thousands of saliva droplets at up to 160km/h (100mph).



Coughed droplets can enter the nose or mouth of innocent bystanders. Meanwhile, germs in settled droplets can live on some surfaces for hours, ready to transfer to an unsuspecting victim.

Each droplet is potentially laden with viruses or bacteria and can travel up to two metres, depending on size.

Researchers at the Massachusetts Institute of Technology, US, have discovered that an invisible gas cloud helps cough droplets to spread around a room. Smaller droplets in the gas cloud are swept around by eddies, travelling further and taking longer to settle.

QUESTION OF THE MONTH

Why were birds the only dinosaurs to survive the mass extinction?

EDWARD SEYMOUR, HOVE

The asteroid that caused the extinction event at the end of the Cretaceous period struck Earth with 60,000 times the energy of the world's entire nuclear arsenal. The atmosphere would have glowed red hot for several hours and all the large dinosaurs that couldn't burrow underground or hide underwater were immediately roasted. When the smaller species came out of hiding they found a charred landscape and the air so thick with soot and sulphur dioxide clouds that sunlight was almost completely blocked out for the next year. It was too dark for photosynthesis, so the herbivores died, then the carnivores. Birds are descended from the maniraptoran dinosaurs but they had two important adaptations that helped them survive. First, they had beaks instead of teeth, which allowed them to crack open seeds and nuts buried in the topsoil. Second, their relatively large skull capacity suggests that they were more intelligent than the other reptiles. They may have lived in more complex social groups that could cooperate and adapt to find new food sources in the radically different post-apocalyptic landscape. This allowed them to eventually outcompete any other species of small dinosaur that might have survived the initial impact. **W**



Caudipteryx was an early maniraptoran feathered dinosaur

WINNER!

Edward Seymour wins an iKettle, (£99.99, smarter.am). Use the app to heat water from anywhere, or schedule it to be ready for when you get home from work. It's compatible with Amazon Alexa and Google Assistant, too!



NEXT ISSUE:

Why do astronauts wear white?

Can plants think?

What is exotic matter?

Email your questions to questions@sciencefocus.com or submit online at sciencefocus.com/qanda

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

FEBRUARY 2018

EDITED BY JAMES LLOYD

01

MUSEUM OF THE MOON
W5, BELFAST
10 FEBRUARY – 4 MARCH 2018.

MARVEL AT THE MOON

It's not quite the Moon on a stick, but this beautiful artwork from Luke Jerram is an uncannily realistic representation of our cosmic companion. Measuring seven metres in diameter, the inflatable moon-balloon uses high-res NASA imagery of the lunar surface and internal lighting to create its mesmeric effect, while a sound installation from composer Dan Jones adds to the ambience. It's been touring the world since 2016, and was photographed here at the Saint-George swimming pool in Rennes, France. Its next stop will be Belfast's W5 science centre, before it heads to UK venues throughout the year (see my-moon.org for the full list of dates).

Jerram has a knack for making art that captures the public imagination. His other projects have included a giant 95m water slide down Bristol's Park Street, a menagerie of microbes rendered as glass sculptures, and *Play Me, I'm Yours*, which has seen more than 1,850 street pianos being installed in cities around the world.





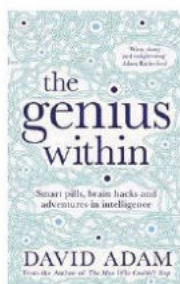
FIND OUT MORE

The making of this artwork is explored in BBC Radio 4's *Why The Moon, Luke?* Listen online at bit.ly/moon_luke

02

GET SMART

**THE GENIUS
WITHIN**
BY DAVID ADAM
OUT 8 FEBRUARY
(£16.99, PICADOR).



Could boosting our brainpower be as simple as swallowing a pill? In his new book, DAVID ADAM turns human guinea pig and tries out some mind hacks for himself. He chats to JAMES LLOYD

What is cognitive enhancement?

Some people would argue that it can include things like brain training and caffeine, but I focus on two methods at the leading edge of neuroscience: smart pills and electrical brain stimulation. The idea is that these tools can be used to change the way the brain works, making us sharper and more focused, for example, or better able to recall facts or spot patterns.

A lot of cognitive enhancers originally came from the medical world, particularly for the treatment of mental disorders. But there's a long tradition of healthy people taking medicines to enhance themselves – the classic example is drugs in sport. Now there's a whole community of people who are experimenting with these brain hacks.

Tell me about your own experiments...

I decided to take the Mensa entrance exam to measure my IQ, and then again a year later, after I'd tried out some of these cognitive enhancers. I bought a brain stimulation kit off the internet for £50, which was an extremely basic device: a 9V battery and two wires, with an electrode at the end of each one. I attached the electrodes to my head using crocodile clips and a saline-soaked sponge, all kept in place by a knitted Spider-Man hat.

How's this device supposed to work?

The nerve cells in the brain use electrical impulses to communicate. The idea behind electrical brain stimulation is that by applying a small current you can make certain neurons more responsive and easily stimulated. By choosing where you place the electrodes, you can target a region of the brain involved in a particular mental or physical activity. This is

all done through the scalp – it's not invasive. When I turned on my device for the first time, I got a bit of a fright, as a flash of light whizzed across my vision – I think it was a side effect of the electric current stimulating my optic nerve.

Is it legal?

There are currently not any regulations around electrical brain stimulation. That's something some scientists aren't happy about, as we still don't have a full picture of how effective it is or what the electricity is doing when it's in there. Smart pills are more of a legal grey area. A lot of these pills are medicines, so they're not illegal but you're supposed to have a prescription. One of the most common smart drugs is modafinil, which is used to treat sleep disorders such as narcolepsy. In the UK, it's not illegal to possess it without a prescription, but it *is* illegal to supply it – unless you're fulfilling a prescription!

How did you get hold of some?

Again, I bought it off the internet. I paid about £60, and then a brown envelope dropped through my letterbox a couple of weeks later. I got the drugs tested at a lab to confirm that they really were modafinil, and then I tried one out. It definitely felt like I could focus much more easily on my task – which was writing this book – and time just seemed more productive. It's like a caffeine hit without the shakes. But I would also say: don't try this at home. There are risks involved with buying things like this off the internet, and we don't know what the long-term side effects of these drugs are.

Did your IQ improve?

In the week leading up to the

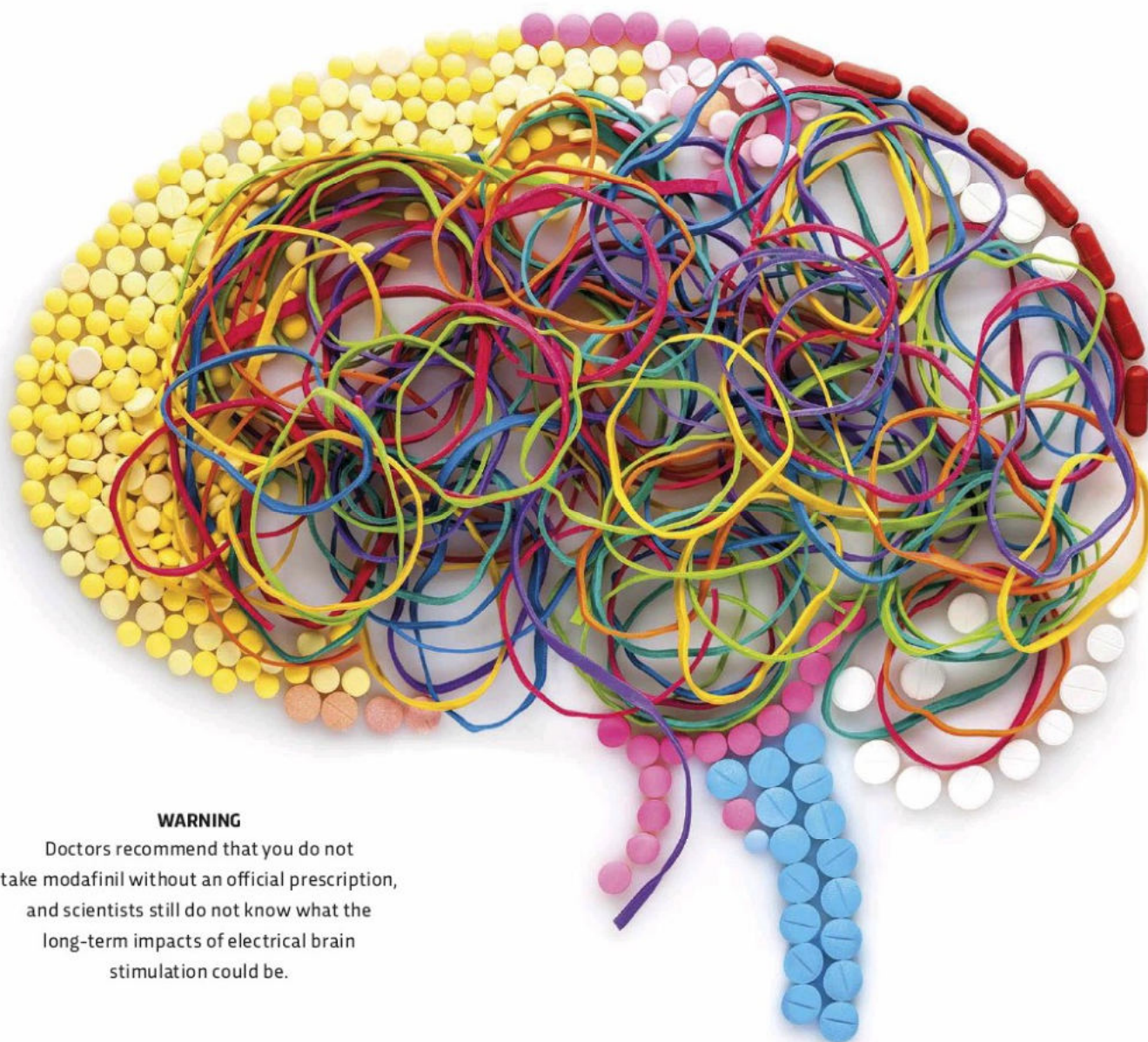
second Mensa test, I stimulated my brain every night, choosing a particular part of the brain that's thought to be involved in lateral thinking, and I also took a modafinil pill on the morning of the test. My IQ did indeed jump up from 125 to 135, which is a significant amount. But this isn't a scientific experiment, of course. Maybe the increase was just down to natural variability, or maybe I was subconsciously trying harder. On the other hand, maybe it was the cognitive enhancement. We'd need a scientific study to find out.

Don't these techniques give an unfair advantage?

If this stuff works, then there are lots of ethical questions. Some of it comes down to how we think about intelligence. In an exam, a smart pill isn't going to plant information in the brain – it has to be there in the first place. So is it giving an unfair advantage? For certain subjects such as maths, which are based more on reasoning, you could argue that it would. But there are lots of other factors that affect people's performances. Some people do better at a particular time of the day; others get crippling anxiety before an exam. Isn't that unfair too?

Do you think cognitive enhancement will ever become widespread?

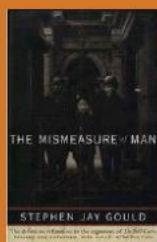
I think it's unlikely that we'll ever have a headset that can completely change someone's performance. But maybe we don't need to – maybe it's just about giving people a boost to help them reach their potential. If a lot of evidence comes out over the next 10 years showing that these techniques are effective, then they're going to become extremely attractive.

**WARNING**

Doctors recommend that you do not take modafinil without an official prescription, and scientists still do not know what the long-term impacts of electrical brain stimulation could be.

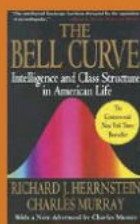
AUTHOR'S BOOKSHELF

Three books that inspired David Adam while writing *The Genius Within*



THE MISMEASURE OF MAN
BY STEPHEN JAY GOULD
(£14.99, W. W. NORTON & COMPANY).

"Flawed but readable polemic on everything from IQ tests to how scientists should approach research on intelligence, and if they should do so at all. The updated second edition is considered the classic rebuttal to the book *The Bell Curve*."



THE BELL CURVE
BY RICHARD J. HERRNSTEIN
AND CHARLES MURRAY
(£16.99, SIMON & SCHUSTER).

"Controversial analysis of real and claimed group differences in IQ. This is not a recommendation or endorsement, but I felt I should read it to judge for myself. The text is more measured than often claimed but it's what one can read between the lines that is disturbing."



SWITCHED ON
BY JOHN ELDER ROBISON
(£9.99, ONEWORLD).

"The latest in a series of books about the author's experiences with autism, this offers a wonderful account of how brain stimulation seemed to activate long-dormant emotional awareness. And the results weren't as positive as you might think."

03

FROM ICE TO FIRE: THE INCREDIBLE SCIENCE OF TEMPERATURE

BBC FOUR, FEBRUARY

CHECK RADIOTIMES.COM FOR DETAILS.**CHILL OUT**

Most of us are like Goldilocks: we don't like things too hot or too cold. But behind the prickliest of heats and the most mind-numbing of colds is some extraordinary science. In her new three-part series, *BBC Focus* columnist Dr Helen Czerski reveals how temperature plays a crucial role in life on Earth, from the inner workings of our cells to the cataclysmic processes that shape entire continents.

Discover where the coldest place in the Universe is, and what happened when Helen plunged into some horrendously cold water. Find out how the Vikings tamed heat to become expert ironworkers, and why the steam engine represented such a huge leap for human progress.

"Temperature is the most fundamental feature of every location in the Universe, dictating what is possible and how quickly things happen," says Helen. "My favourite bit of the series was being the first crew to film the UK's new polar research ship being built [the *RRS Sir David Attenborough*], and to see the ingenious engineering that will keep it safe in the Arctic and Antarctic waters."



04

CONTAGION! THE BBC FOUR PANDEMIC

BBC FOUR, 27 FEBRUARY.

PREPARE FOR THE NEXT PANDEMIC

A century since the Spanish flu pandemic took up to 100 million lives worldwide, influenza is still causing problems. With the viruses constantly evolving to outsmart their hosts, many experts agree that it's only a matter of time before the next flu pandemic races around the globe.

So what can we do about it? In an ambitious citizen science experiment for BBC Four, mathematician Dr Hannah Fry and emergency medic Dr Javid Abdelmoneim have created a virtual pandemic using a specially-created app. In this 90-minute special, we'll follow Hannah as she adopts the role of Patient Zero, launching the outbreak on the streets of Surrey. Will she be able to persuade enough people to download the app? And, if she does, what can the dataset tell us about how a deadly flu virus might spread across the UK, and how it might be slowed?

Meanwhile, Javid looks at the latest research that's aiming to stop flu in its tracks. He explores a project that's infecting healthy volunteers with virus cells, with the aim of finding out why some people are especially contagious (so-called 'super-spreaders'), and visits a factory that will produce vaccines when the next pandemic emerges.

PHOTO: ROBERT HOLLINGWORTH, MUSEUM OF LONDON, BBC

05 SEE THE FATBERG

FATBERG!

MUSEUM OF LONDON
9 FEBRUARY – 1 JULY
FREE ENTRY.

Last September, Thames Water made a startling discovery. Lurking in the sewers beneath Whitechapel was a monstrous 130-tonne 'fatberg'. Now, the Museum of London is putting it on display. We asked SHARON ROBINSON-CALVER, head of conservation and collection care at the museum, how they made it happen

What makes a fatberg?

A fatberg is a congealed mass of fats, oils and greases, plus things that go down the toilet that shouldn't be flushed, such as nappies, wet wipes, sanitary products and condoms. So pretty unpleasant really! The Whitechapel fatberg really captured the public imagination because it was the biggest one that we'd ever found – over 250 metres long.

Why did the Museum of London decide to display a fatberg?

Many of the items in our collection have been discovered in cesspits – things such as teapots, bottles and coins – and these tell us a lot about how people once lived. In some respects, fatbergs are no different – they're human-made objects that reflect modern issues such as population expansion, changes in diet, and the pressures we're putting on London's Victorian sewer system. It's an important part of the story of the city, showing the challenges that urban living can create.

How did you go about getting a sample?

When we first heard about the monster fatberg, we asked Thames Water to take some samples for us. To excavate it, they blast the fatberg with high-pressure water jets, breaking it into smaller chunks that can be sucked up into a tanker. The fatberg is toxic – it off-gasses carbon monoxide and hydrogen sulphide, and there's a real risk of bacterial diseases – so we spent some time analysing the samples to understand how we could handle and display them safely.

What's the best solution you came up with?

Once we'd X-rayed the samples to check for things like hypodermic needles, we slowly air-dried them at room temperature, which turned them from their sloppy, mushy consistency to the harder, more oxidised material that you get sticking to the sewer walls. Once it's dried and been left to off-gas, the material becomes chemically stable enough to

display – in a protective case of course! The original fatberg has now been removed from the sewer and converted into biodiesel, so we'll be displaying the last remaining piece – it's about the size of a shoebox.

What does the fatberg smell like?

I didn't come face-to-face with the original fatberg, but I've been told that it smelled like a combination of rotting meat and rotting nappies. By the time I got to experience it myself, several weeks later,

it wasn't quite so bad – more like dirty toilets.

How can we stop fatbergs from forming in the first place?

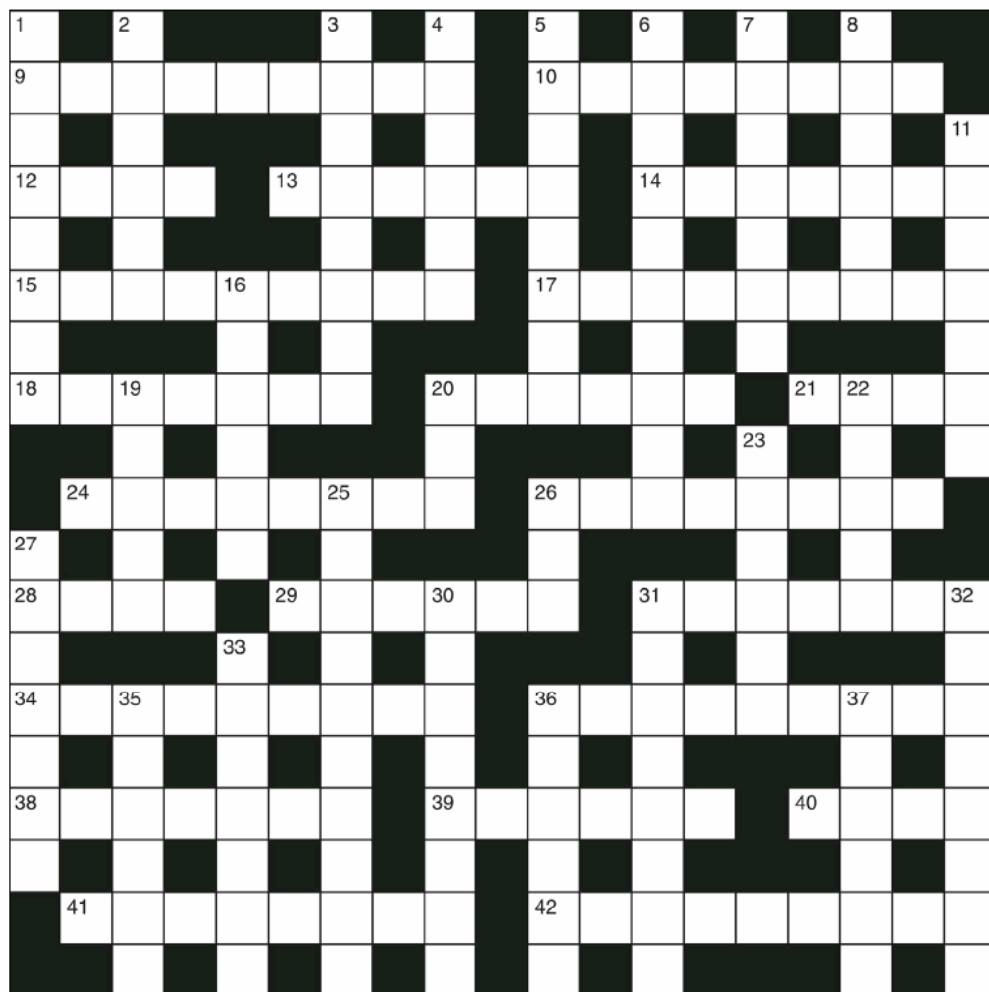
There are around 300,000 sewage blockages in the UK every year, and wet wipes make up 93 per cent of the problem. So the message from Thames Water is only to flush the three 'p's down the toilet: poo, pee and toilet paper. And put cooking fats and oils in the bin, not down the sink.



Yes, this is the nicest picture we could find...

BBC FOCUS CROSSWORD

GIVE YOUR BRAIN A WORKOUT



DOWN

- 1 Racy robe worn by fast driver (3,5)
- 2 Old tales revolving around bones (6)
- 3 Rubs carelessly – it's a pain in the shoulder (8)
- 4 Engineers have a brace to fix (6)
- 5 A group of detectives managed to contain one form of pollution (4,4)
- 6 Storage for starch puts locale out (10)
- 7 Greeting fable from the past (7)
- 8 Tethering lieutenant with a song (6)
- 11 Suit a high-pitched instrument (7)
- 16 Wives get sick round tree (6)
- 19 Nutrition gets left – it's a disaster (5)
- 20 Howl from an alcove (3)
- 22 Start playing notes (5)
- 23 Pressure to formulate a rule about the lungs (6)
- 25 Greek scientist building new semi with journalist (10)
- 26 Vehicle with its own set of conductors (3)
- 27 German solved clue, so found sugar (7)
- 30 Learn ode about a shrub (8)
- 31 Disinfectant caused stomach pain around bar, sadly (8)
- 32 Clerk may be a soprano or a tenor (8)
- 33 Skilful with a French key that's inoperative (7)
- 35 Musical agreement (6)
- 36 Excessive supply, with space for protein mixture (6)
- 37 Distant handset (6)

ACROSS

- 9 Arrange a shoot and employ a kiln (9)
- 10 Call Eric terribly priestly (8)
- 12 Artist takes fellow to be a bird (4)
- 13 When sentry heard of divine residence (6)
- 14 Swimmer needs money to get terribly fit (7)
- 15 Depreciation from one of the taps (4,5)
- 17 Equipment tears us apart about father (9)
- 18 Offers, as a prize, a gentleman thief (7)
- 20 Chicken giving weight to a boxer (6)
- 21 Return of a large youngster (4)
- 24 Glow by railway causes heart problem (8)
- 26 Food poisoning throws limbs out (8)
- 28 The game I play in Latin (4)
- 29 A sign, like this clue (6)
- 31 Bunch caught by desire and hesitation (7)
- 34 Cite a ruse to improve burn (9)
- 36 Cigar rite carried out for old person (9)
- 38 Fit for occupation (7)
- 39 Run one off in a cell (6)
- 40 The ruler in the mirror (4)
- 41 Building material that's not imaginary (8)
- 42 Pretence about finding current in middle (9)

ANSWERS

For the answers, visit bit.ly/BBCFocusCW
Please be aware the website address is case-sensitive.



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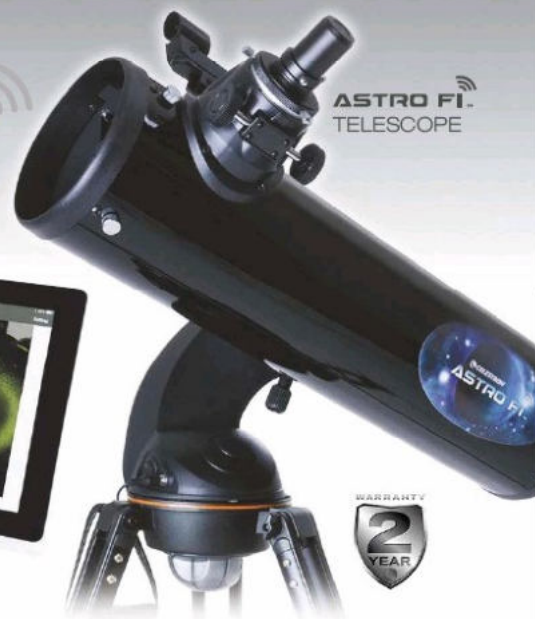
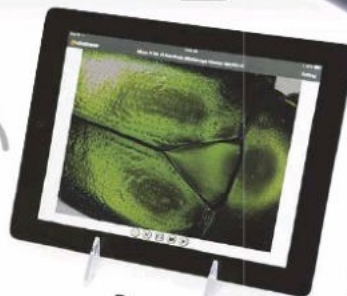
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Dr Susan Finkbeiner

This month, **Dr Susan Finkbeiner** from the University of Chicago talks to **Helen Pilcher** about catching butterflies in the jungle and strutting her stuff on the catwalk

Much of Susan's work focuses on *Heliconius* butterflies. The bright colours seen in this genus warn predators that they taste unpleasant.

What is it that you do?

I study evolution of patterns in butterfly wings. I often spend months at a time working in jungles in places like Costa Rica, Ecuador and Panama.

What's that like?

Some of the field sites are really remote. There's one in Ecuador that takes 15 hours to get to from Quito, via bus, 4x4 and boat. It's surrounded by scattered indigenous communities so you get the opportunity to see what their way of life is like. Every now and then, the kids bring you cool animals to see like baby monkeys.

What do you do in the jungle?

Sometimes we just collect butterflies. They're high in the

canopy, so our nets are up to nine metres long. It takes a lot of practice to catch a butterfly at that range. Other times, we study predation, so we lay out hundreds of fake, paper-winged butterflies then return later to see whether or not they have been nibbled by birds.

Is your fieldwork dangerous?

When living in a city, my biggest worry is missing a train or having a bad hair day. But in the field, you have to worry about deadly snakes, being stung by really gnarly and nasty arthropods, or being stalked by howler monkeys.

You've been stalked by a monkey?

I've been peed on by howler monkeys. More than once. They can be loud if they want to shoo

you away, or they can be quiet and then all of a sudden you think it's raining! It could be worse though. Capuchin monkeys are notorious for going to the bathroom in their hand and then throwing it at you.

How did you end up being a model?

When I was in high school I did beauty pageants, but I knew my heart was with science. I thought about it again recently and realised that if I became a model, I could help crush stereotypes. I think it's important to show that models can be smart and have other interests, and that scientists don't have to be stuck in the lab all the time. I want to show that you can be girly and dress up, and at the same time be a scientist and go running around in a muddy jungle. So I signed up with a modelling agency in Boston.

You recently modelled at London Fashion Week. What was that like?

It's like being Cinderella for a weekend. I get to wear amazing outfits made by up-and-coming designers who have made clothes for the likes of Katy Perry and Paris Hilton. On the catwalk, the goal is not to walk too fast, because that's your instinct if you're nervous. It's also a real challenge not to smile.

Do we need more entomologists?

Absolutely. I think everyone has an entomologist in them when they're young, but then grow out of it for all sorts of reasons. Maybe their parents tell them it isn't a real job. But the reality is that I make a living from going into the Amazon and collecting butterflies. I want to communicate to young people that they should never lose their passion for science and that there's always a way to follow your dreams. 🦋

Dr Susan Finkbeiner is a postdoctoral researcher who studies the evolution of butterfly wing patterns. She tweets from @Fink_about_it

DISCOVER MORE



To listen to episodes of *The Life Scientific* with top scientists, visit bit.ly/life_scientific

NEXT ISSUE: DR ZOE WILLIAMS

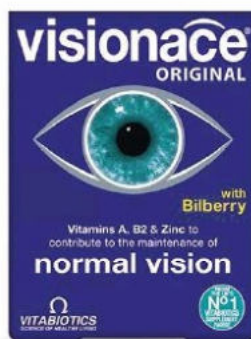
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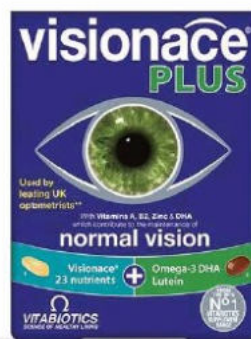
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